



Tevatron, LHC and CTEQ4LHC

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High Precision for Hard Processes at the LHC 2

Some references

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Hard interactions of quarks and gluons: a primer for LHC physics

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Abstract

In this paper, we will develop the perturbative framework for the calculation of hard-scattering processes. We will undertake to provide both a reasonably rigorous development of the formalism of hard-scattering of quarks and gluons as well as an intuitive understanding of the physics behind the scattering. We will emphasize the role of logarithmic corrections as well as power counting in α_s in order to understand the behaviour of hard-scattering processes. We will include ‘rules of thumb’ as well as ‘official recommendations’, and where possible will seek to dispel some myths. We will also discuss the impact of soft processes on the measurements of hard-scattering processes. Experiences that have been gained at the Fermilab Tevatron will be recounted and, where appropriate, extrapolated to the LHC.

(Some figures in this article are in colour only in the electronic version)

Review

Jets in hadron–hadron collisions

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Abstract

In this article, we review some of the complexities of jet algorithms and of the resultant comparisons of data to theory. We review the extensive experience with jet measurements at the Tevatron, the extrapolation of this acquired wisdom to the LHC and the differences between the Tevatron and LHC environments. We also describe a framework (SpartyJet) for the convenient comparison of results using different jet algorithms.

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Keywords: Jet; Jet algorithm; LHC; Tevatron; Perturbative QCD; SpartyJet

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More references

- If you're rushed for time

explain it in 60 seconds



Symmetry
A joint Fermilab/SLAC publication
PO Box 500
MS 206
Batavia Illinois 60510
USA

symmetry

Donald Rumsfeld

- Unlike at the first HPP conference, I will not be referring to Donald Rumsfeld



-
- Besides, who needs to, now that we have Sarah Palin



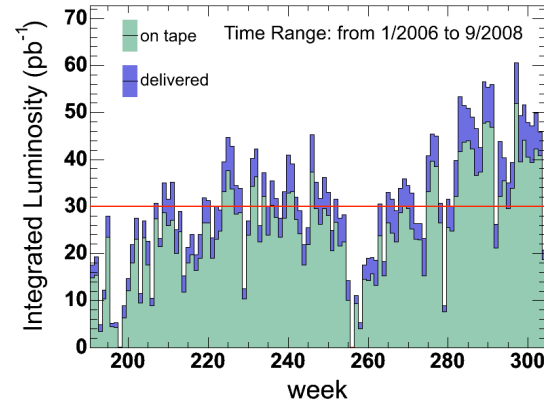
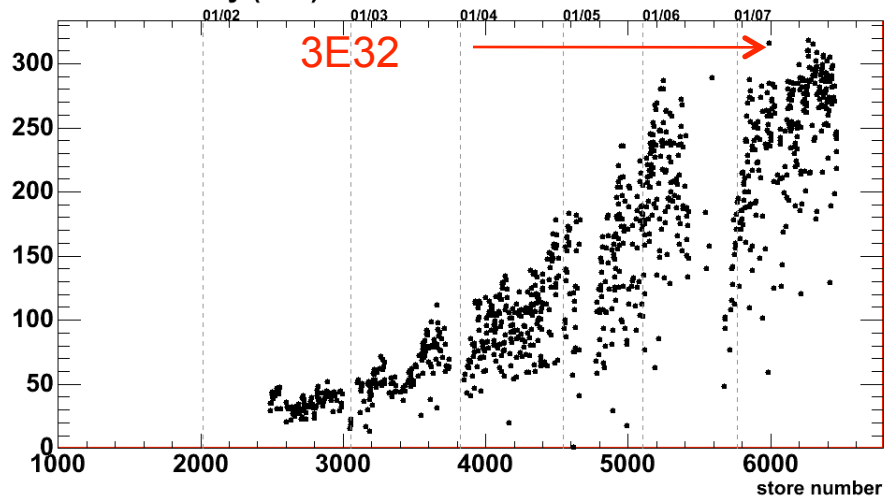
Tevatron



Because of laziness on my part, most results are from CDF

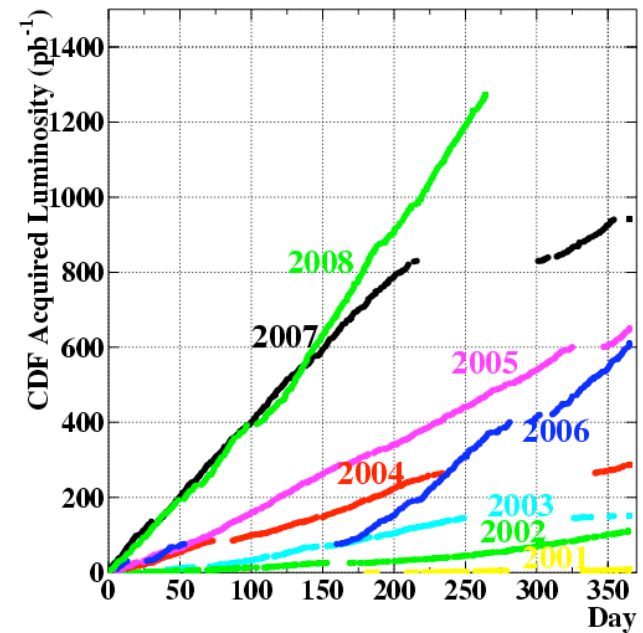
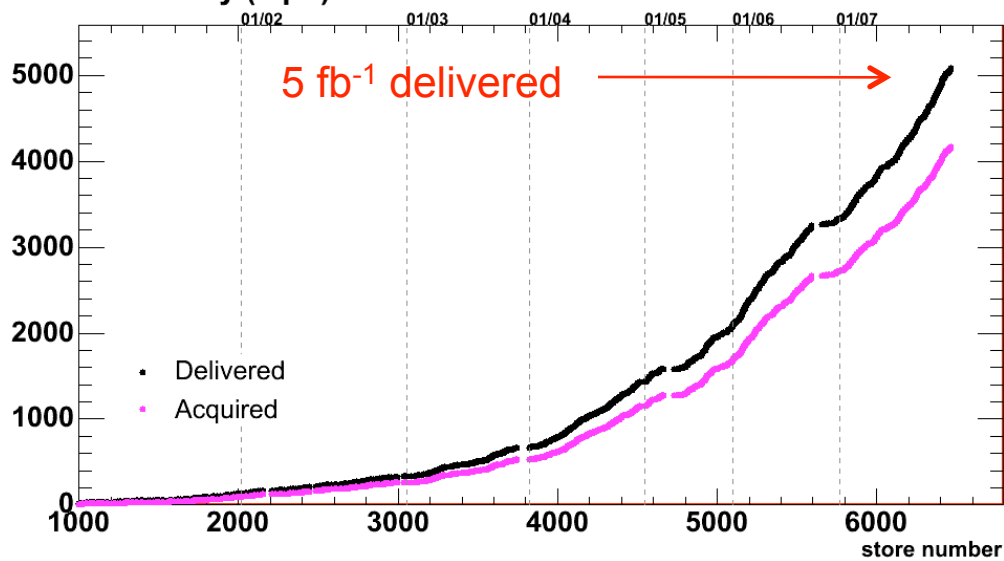
Luminosity

Initial Luminosity (E30)



40 $\text{pb}^{-1}/\text{week}$
accumulated

Luminosity (1/pb)



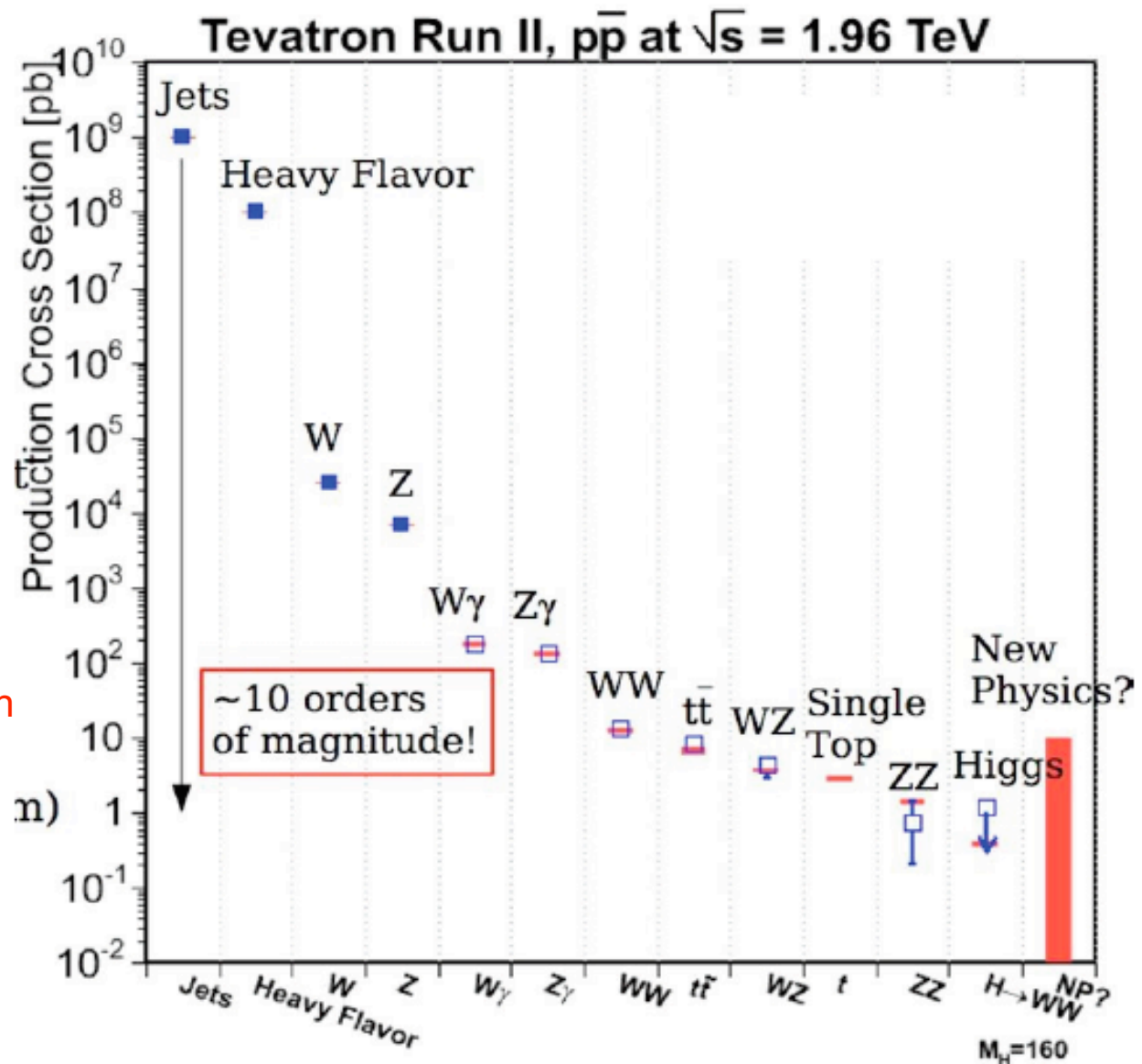
Tevatron physics

physics over a broad range of cross sections, with mature detector, reconstruction and analysis techniques

100 new results in last 12 months

many analyses with 3 fb^{-1} , to come with 4

publication or dissertation every 4.5 days



Inclusive jet production

- This cross section/ measurement spans a very wide kinematical range, including the highest transverse momenta (smallest distance scales) of any process
- Note in the cartoon to the right that in addition to the $2 \rightarrow 2$ hard scatter that we are interested in, we also have to deal with the collision of the remaining constituents of the proton and anti-proton (the “underlying event”)
- This has to be accounted for/ subtracted for any comparisons of data to pQCD predictions

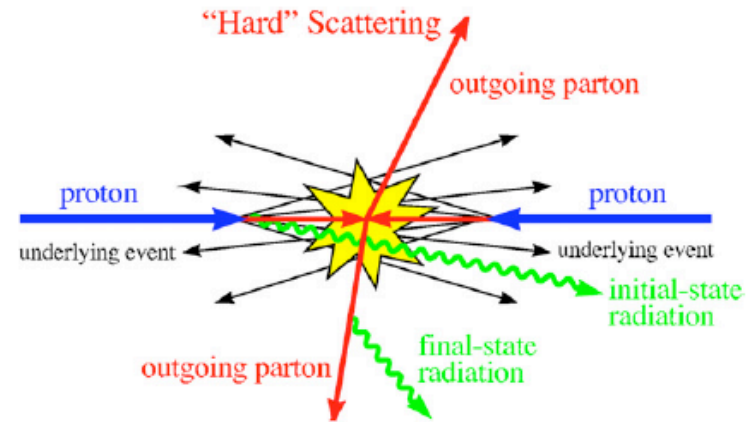
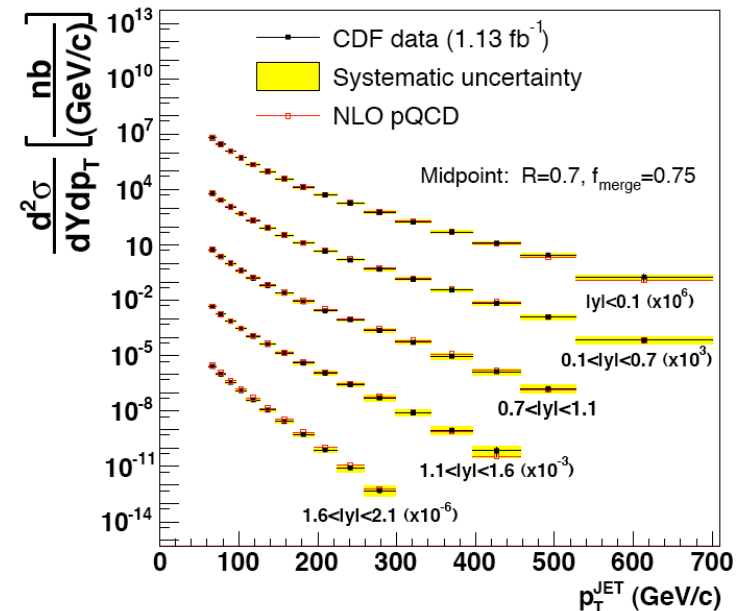


Figure 43. Schematic cartoon of a $2 \rightarrow 2$ hard-scattering event.



Corrections

- Hadron to parton level corrections
 - ◆ subtract energy from the jet cone due to the underlying event
 - ◆ add energy back due to hadronization
 - ▲ partons whose trajectories lie inside the jet cone produce hadrons landing outside
 - ◆ the hadronization corrections will be similar at the LHC, while the UE corrections should be much larger
- Result is in good agreement with NLO pQCD predictions using CTEQ6.1 pdf's
 - ◆ pdf uncertainty is similar to experimental systematic errors
- Result is also in good agreement with CTEQ6.6

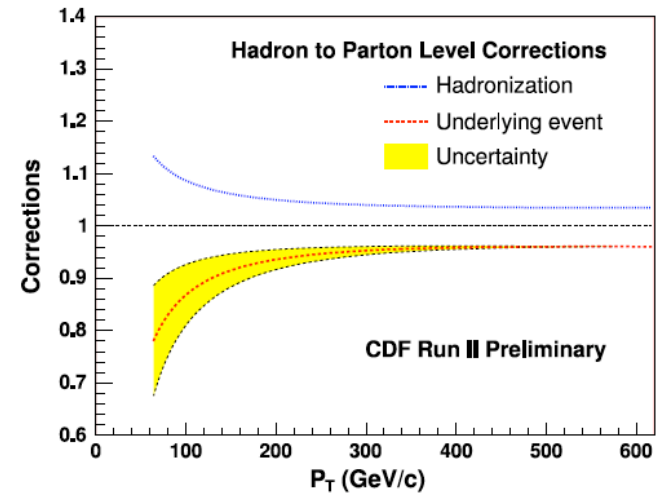


Figure 48. Fragmentation and underlying event corrections for the CDF inclusive jet result, for a cone size $R = 0.7$.

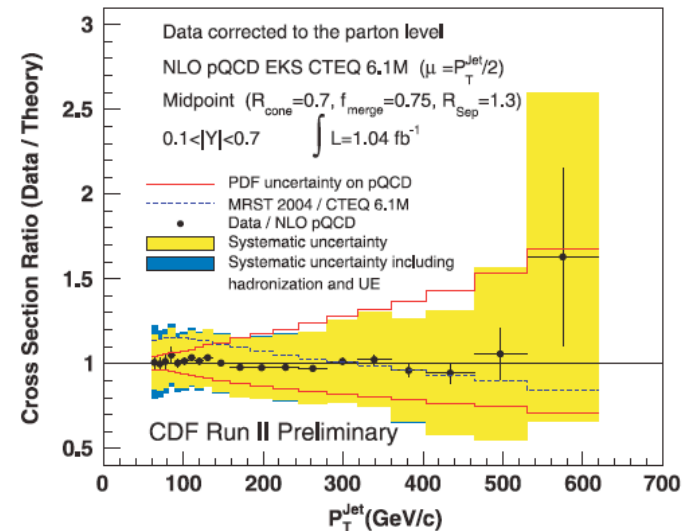
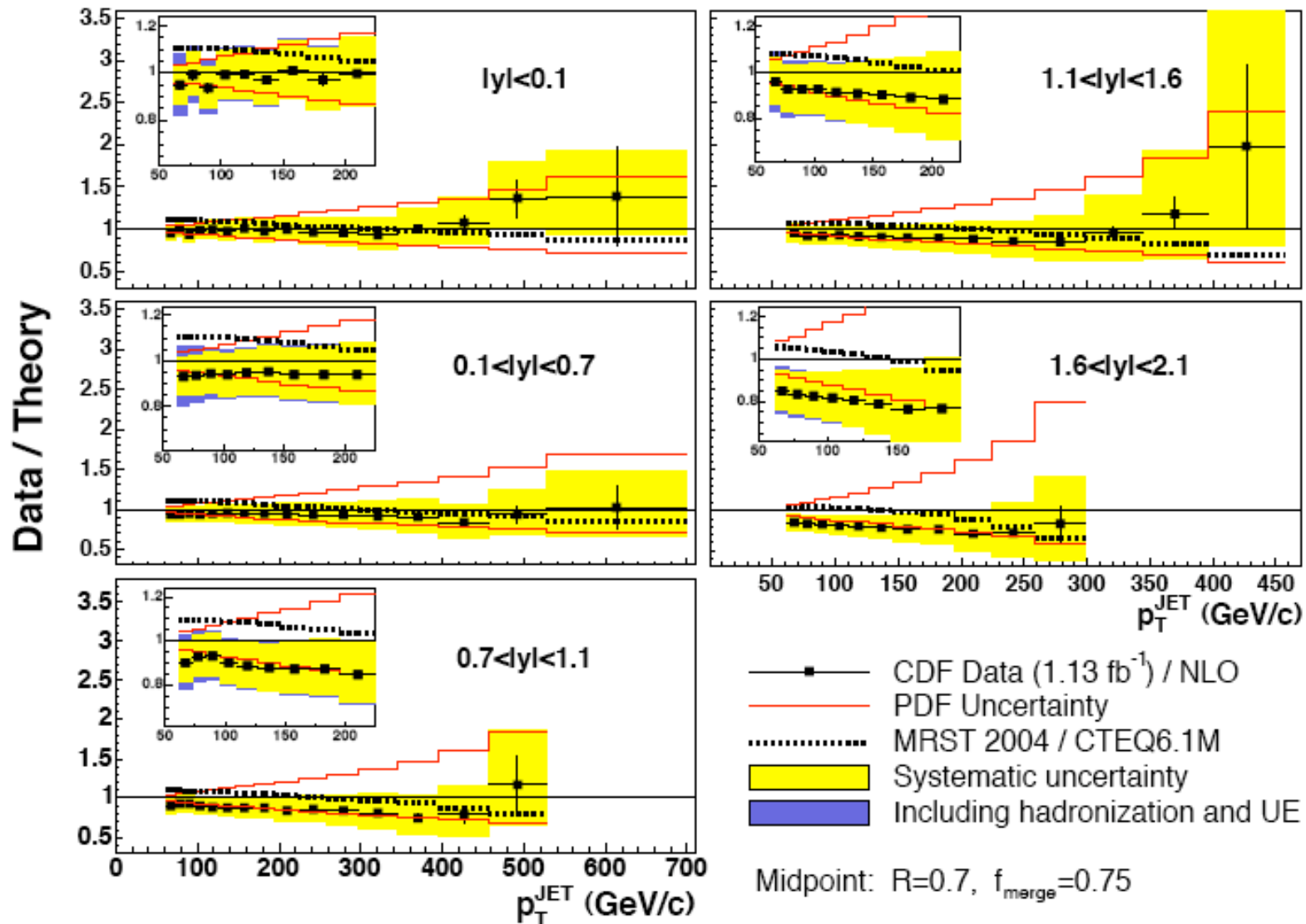


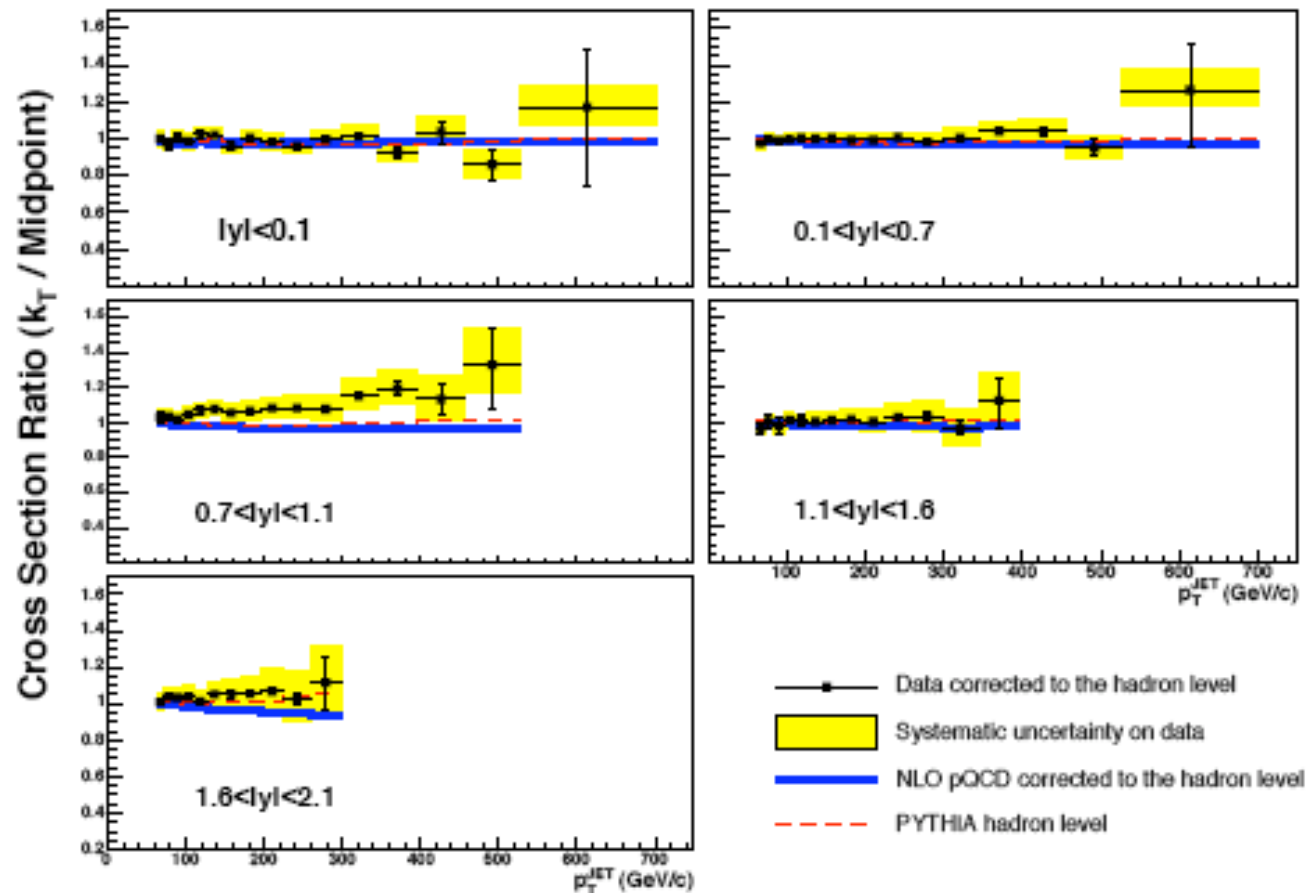
Figure 49. The inclusive jet cross section from CDF in Run 2 compared on a linear scale to NLO theoretical predictions using CTEQ6.1 and MRST2004 pdfs.

Data to theory



Other algorithms

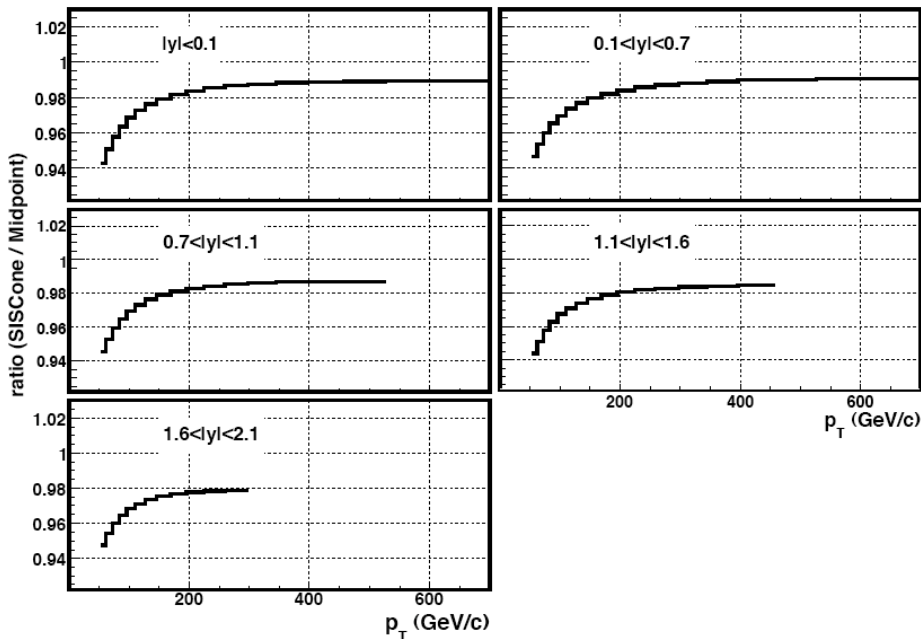
- The results for the k_T algorithm are in agreement with those for the Midpoint algorithm
- k_T algorithm works in hadron-hadron collider



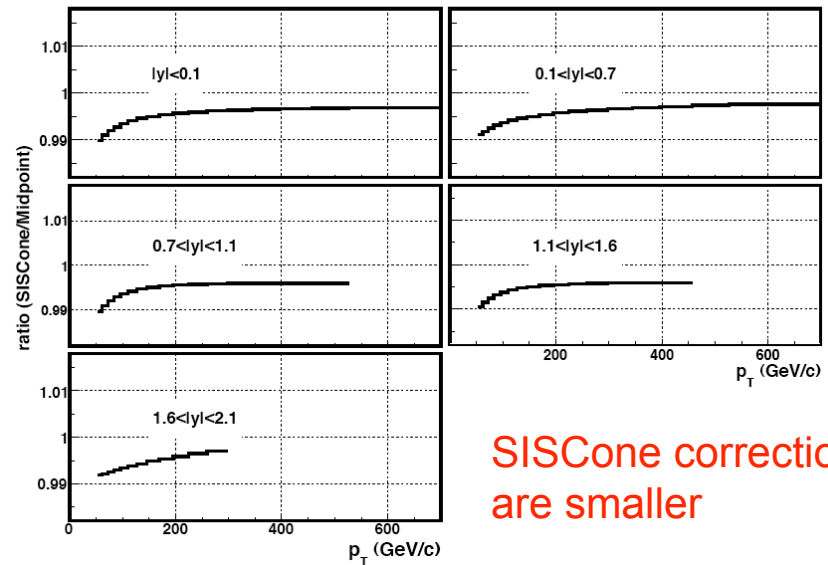
SISCone vs Midpoint

- The SISCone jet algorithm developed by Salam et al is preferred from a theoretical basis, as there is less IR sensitivity from not requiring any seeds as the starting point of a jet

Hadron Level: Midpoint versus SISCone



Parton Level (UE off): Midpoint versus SISCone

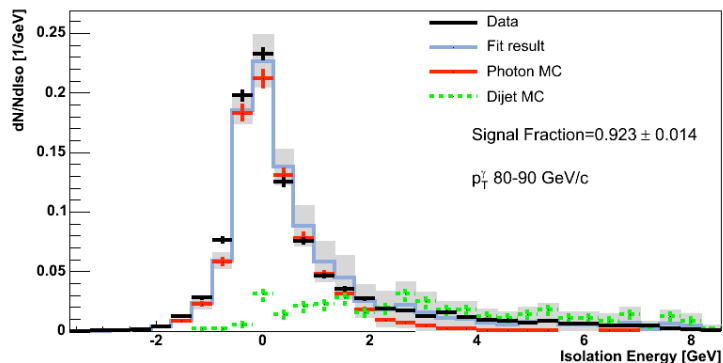
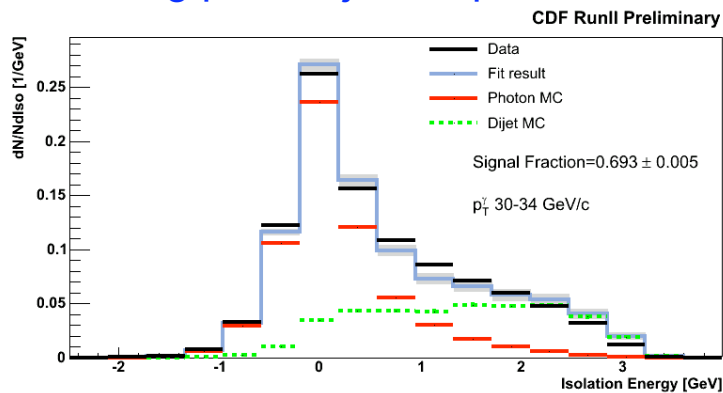


SISCone corrections are smaller

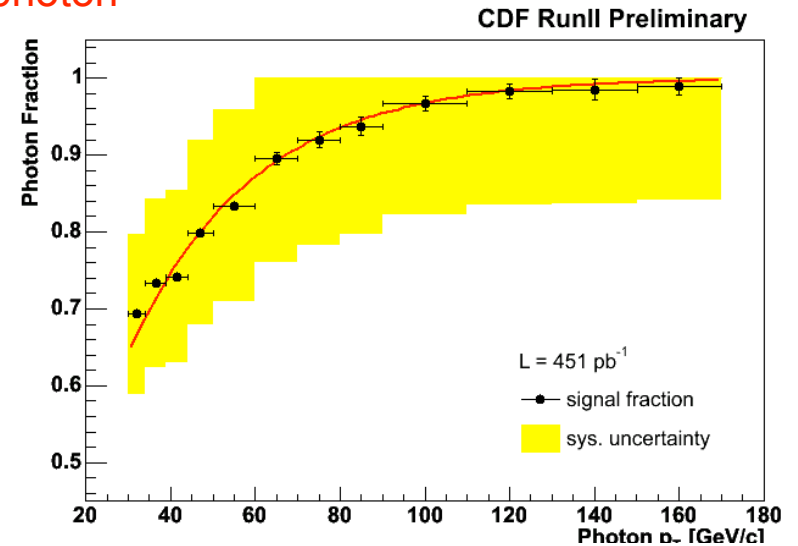
- So far, at the Tevatron, we have not explicitly measured a jet cross section using the SISCone algorithm, although studies are underway, but we have done some Monte Carlo comparisons for the inclusive cross sections
- Differences of the order of a few percent at the hadron level reduce to $<1\%$ at the parton level

Inclusive photons

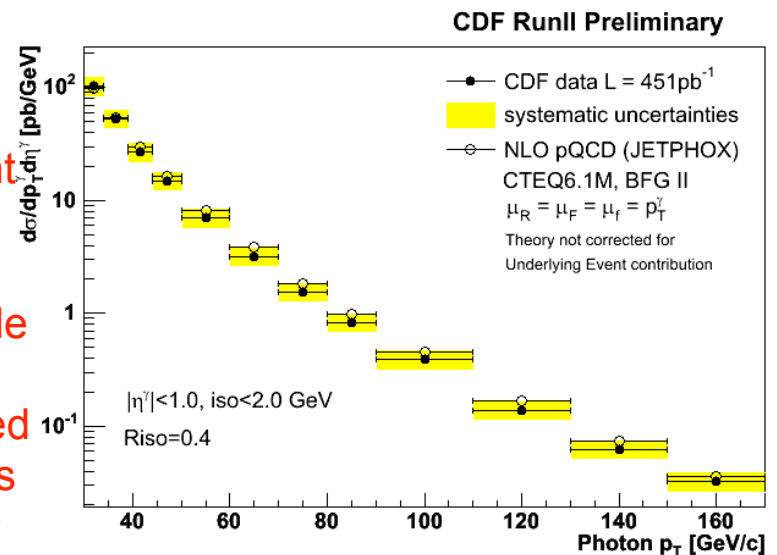
- Photons are required to have less than 2 GeV of energy in an isolation cone of radius 0.4 around the photon candidate
- Photon fraction (already high at 30 GeV due to isolation cut) is fit by using photon/jet templates



an isolated high p_T photon candidate is a photon

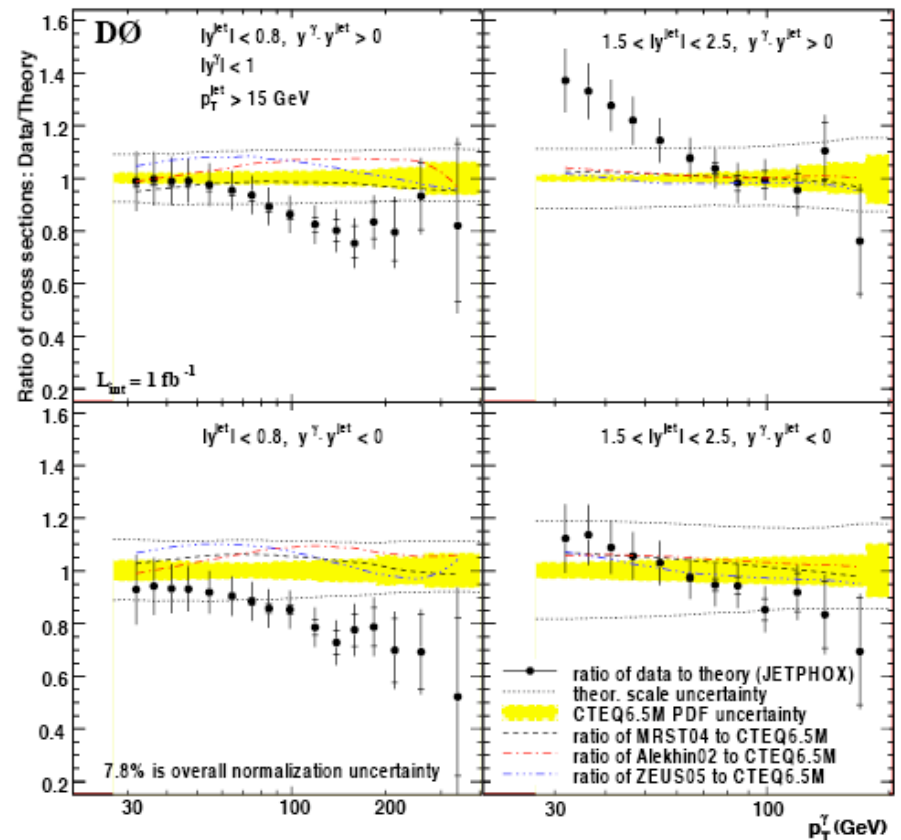
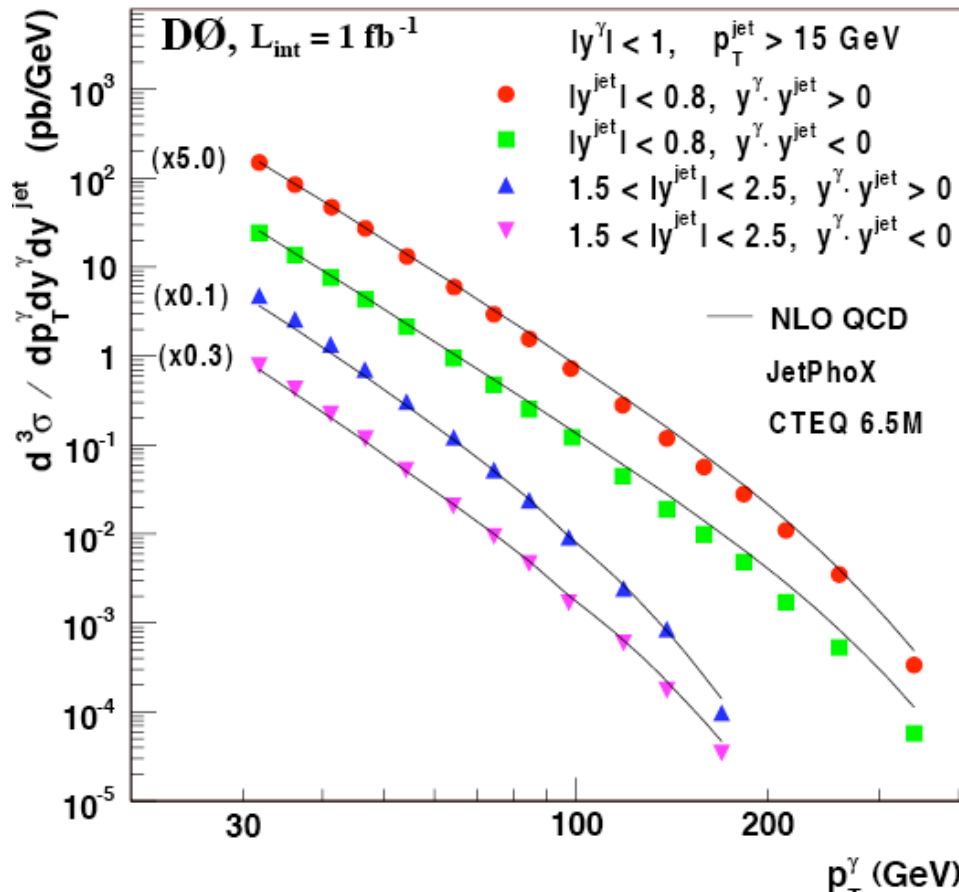


good agreement with NLO; there's a linear scale plot that's not blessed that shows this better

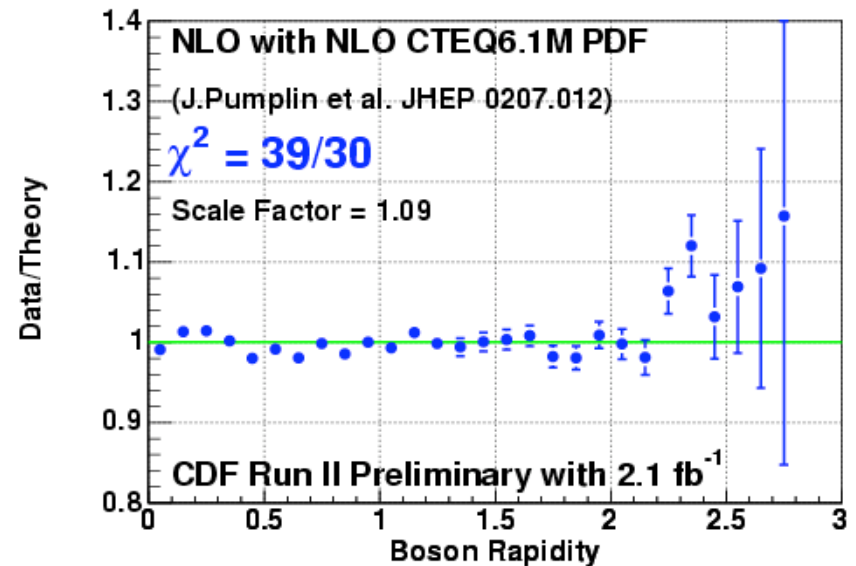
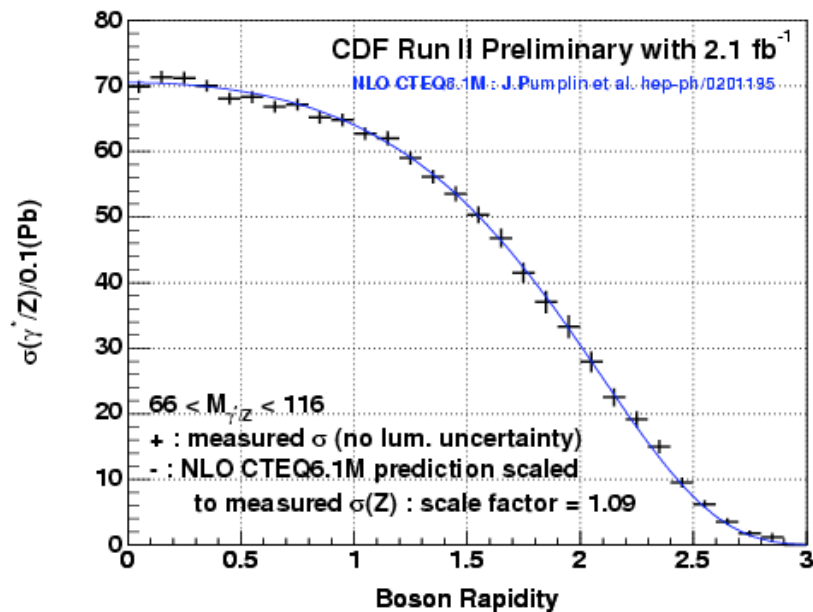


Photon + jet

- ...but photon + jet measurements from D0 do not agree with NLO QCD predictions
- Currently under investigation in CTEQ (as part of CTEQ4LHC)

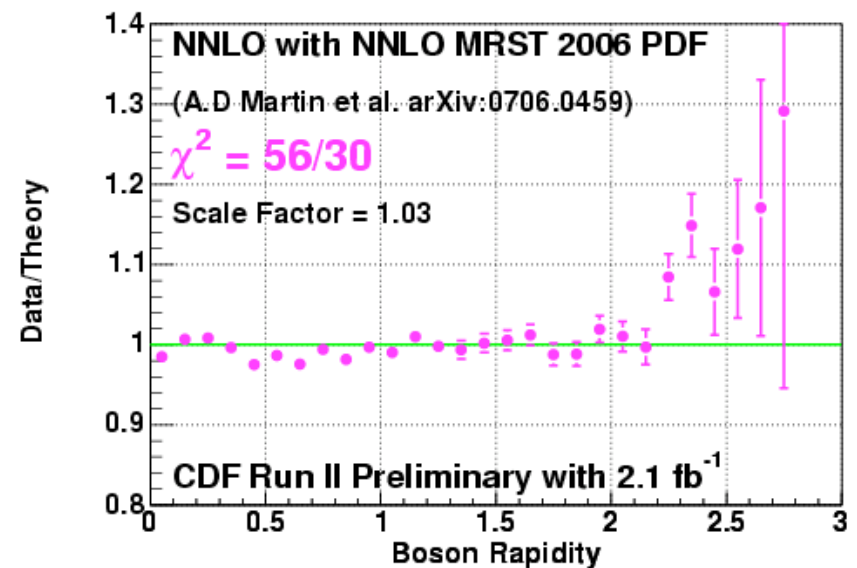


Z rapidity distribution

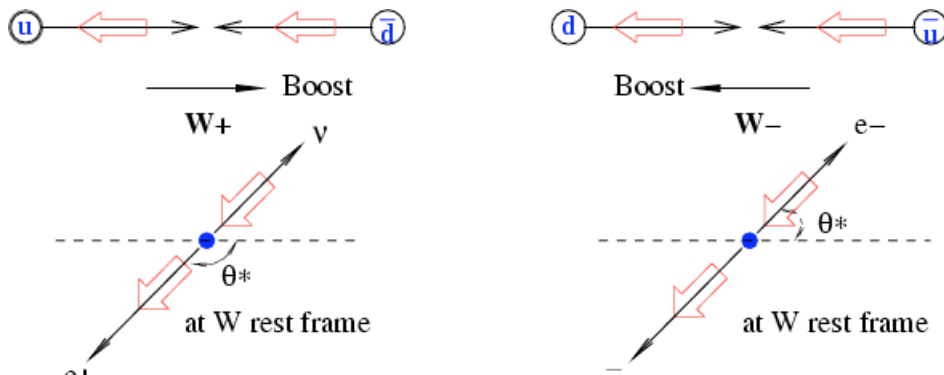


small statistical and systematic errors

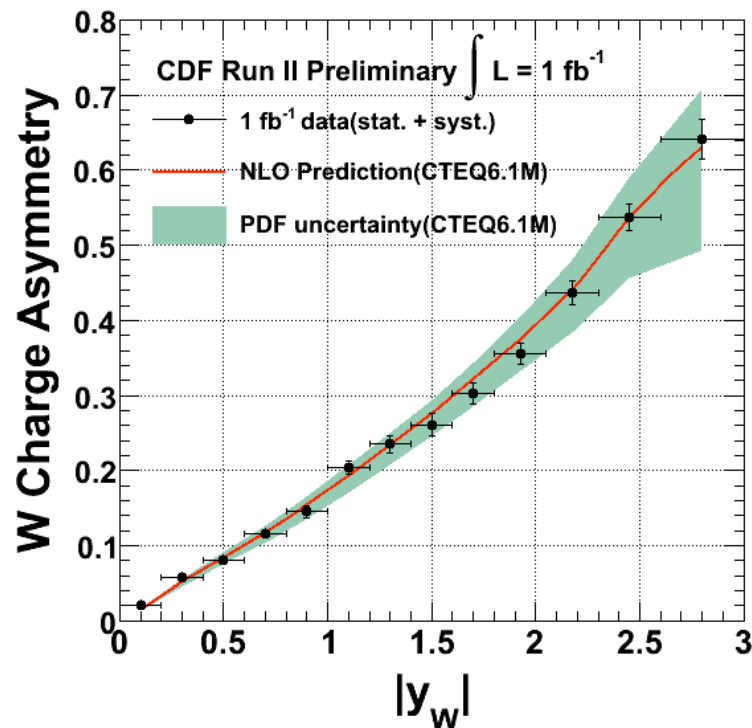
being included in new CTEQ global pdf fits



W asymmetry



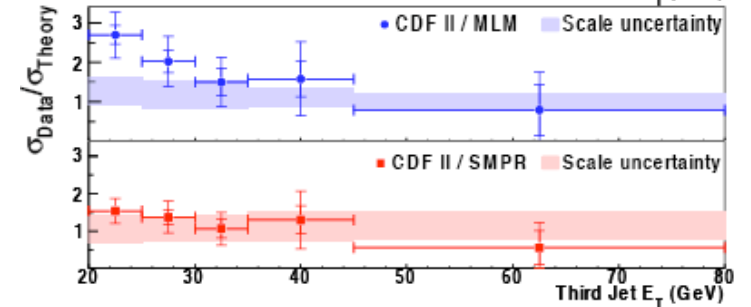
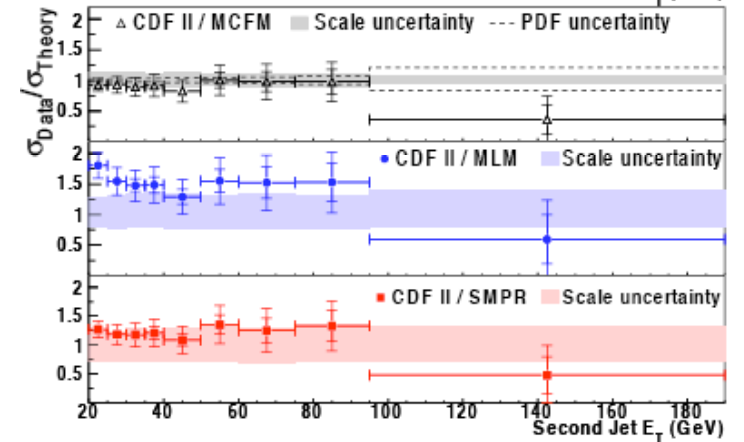
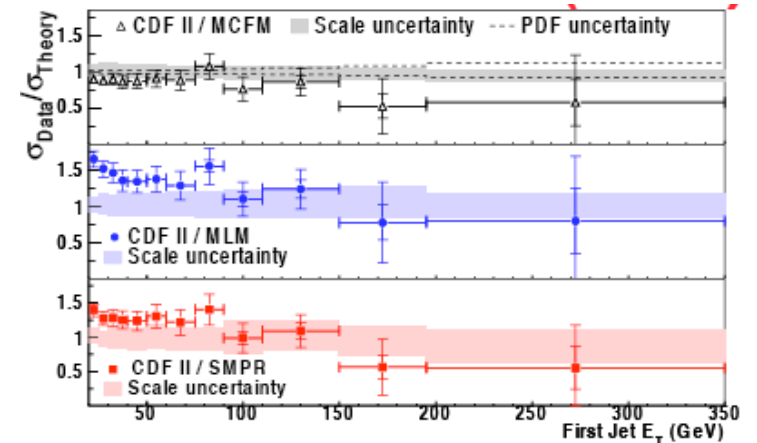
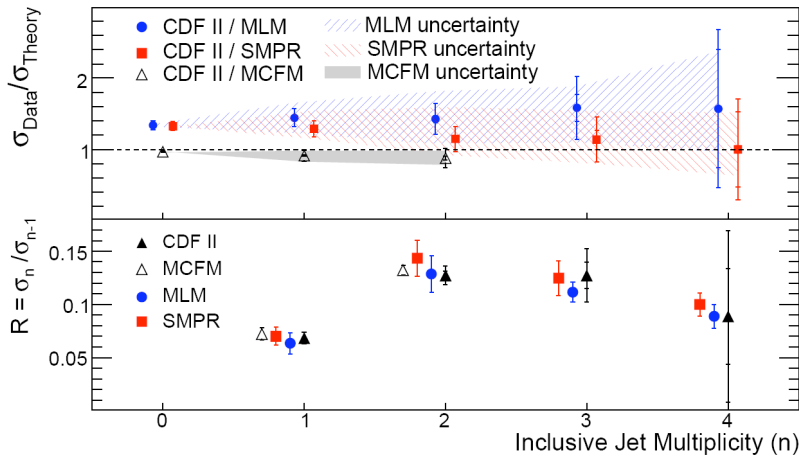
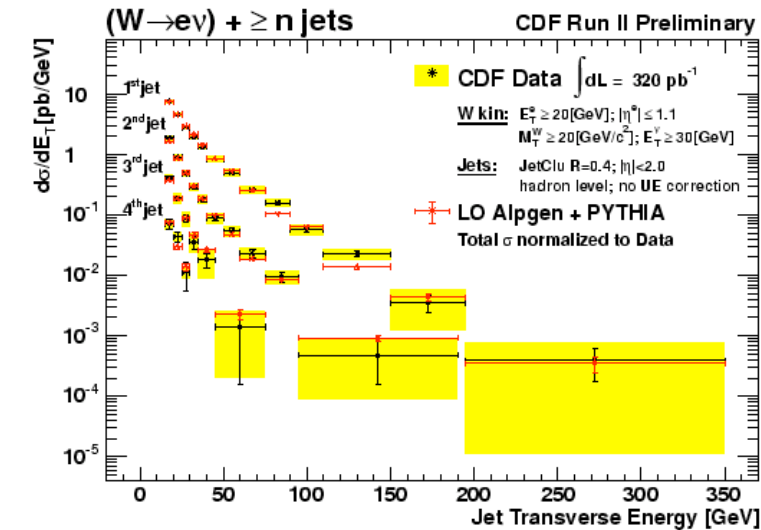
- New measurement of the W asymmetry which directly reconstructs the W rapidity
- The relative contributions of the two possible neutrino solutions are determined using the V-A decay structure of the weak interaction and the dependence of the W boson rapidity on the differential cross section $d\sigma/dy$



◆ being included in CTEQ fits

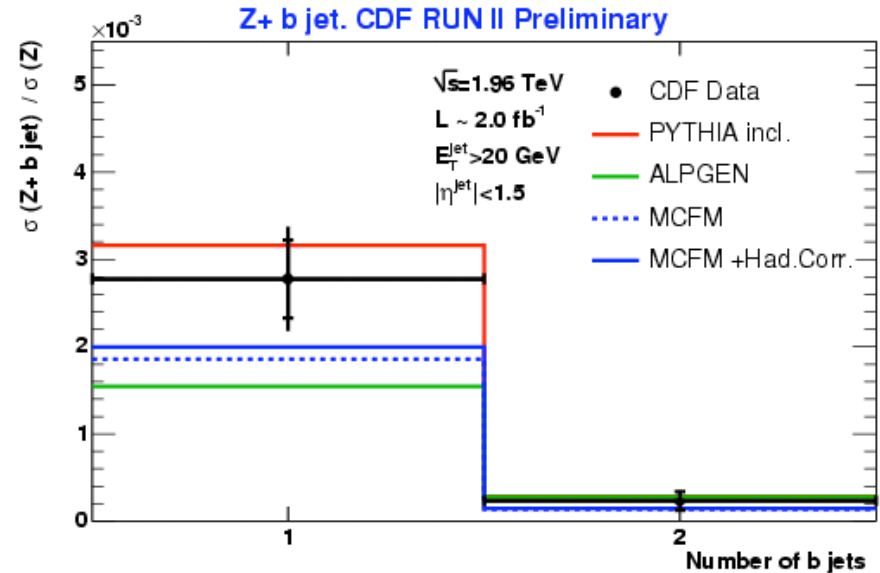
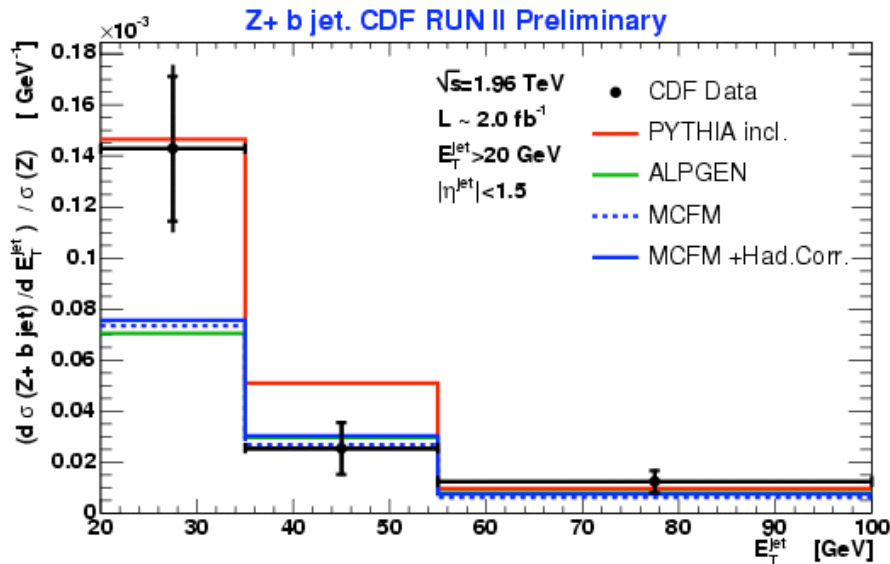
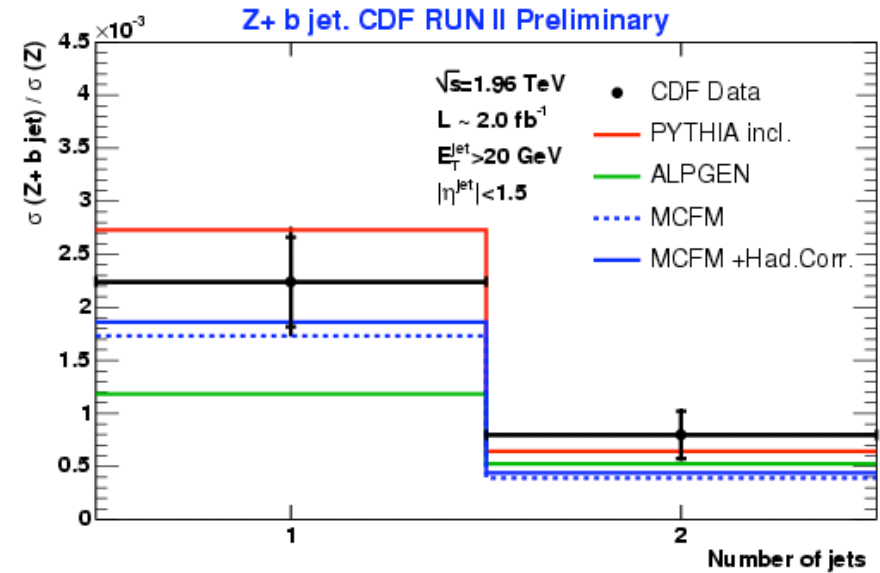
W/Z + jets

- Cross sections have been corrected back to hadron level to allow for direct comparison to theoretical predictions



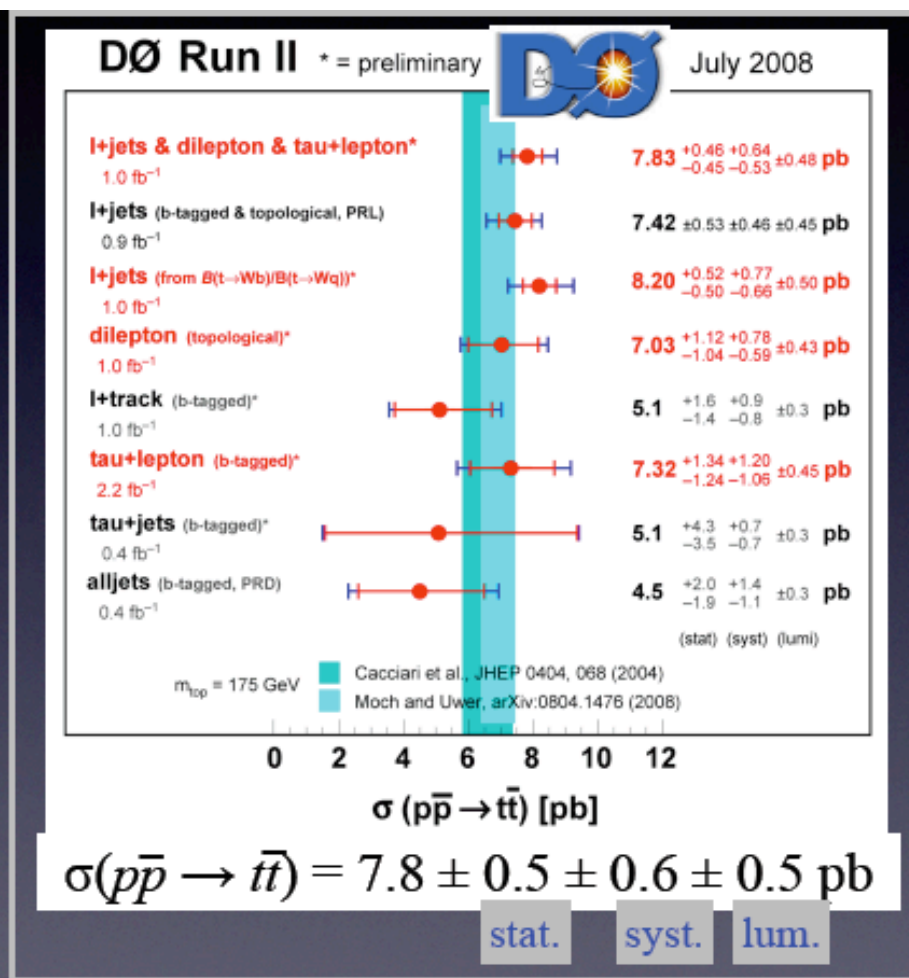
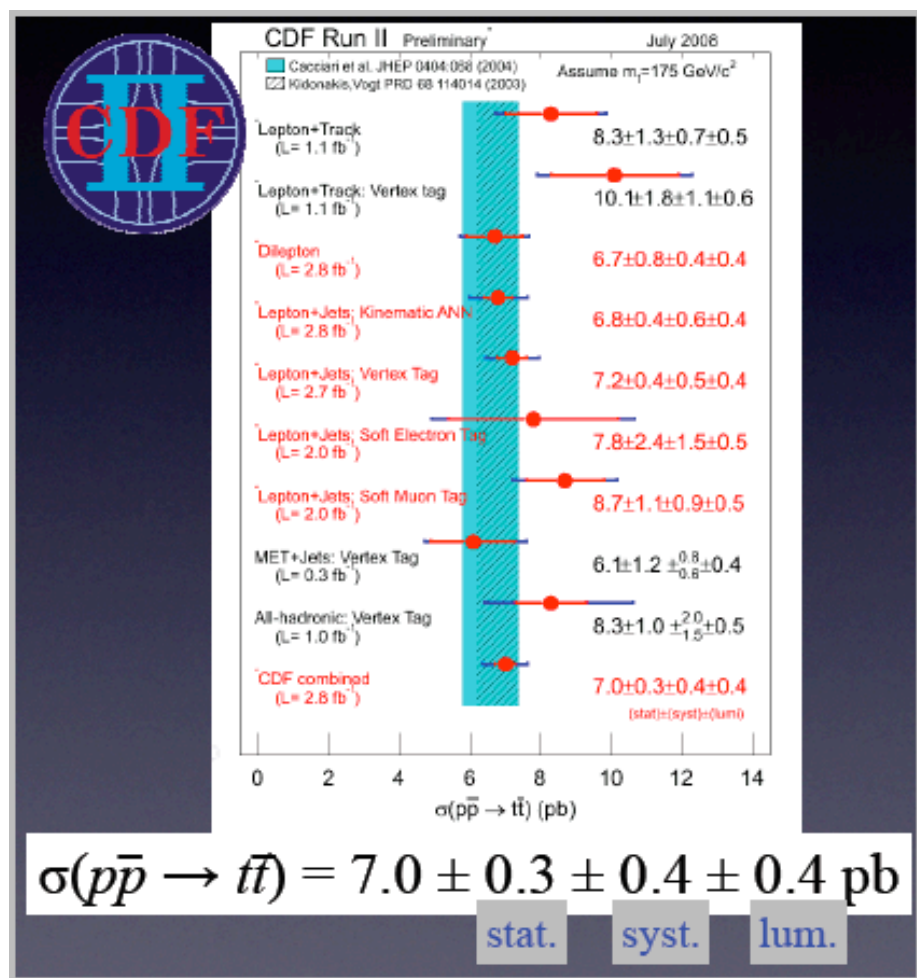
Z + b jet(s)

- Require a secondary vertex and then fit the vertex mass to determine the b fraction
- An excess at low E_T for the b jet



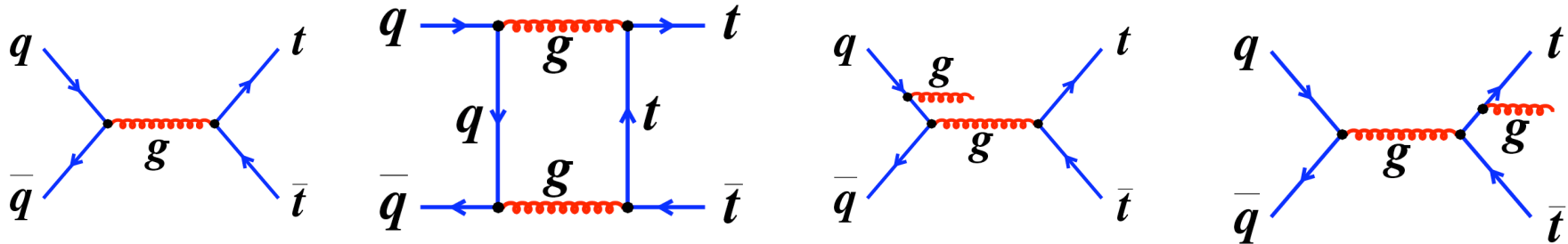
Top production

- Statistical errors now smaller than systematic errors
- Total error < 10%
- Without luminosity error, ~7% (see later)

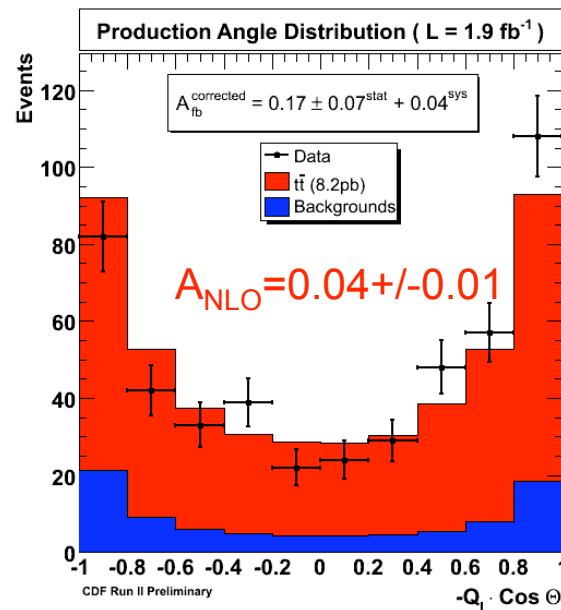


tT asymmetry

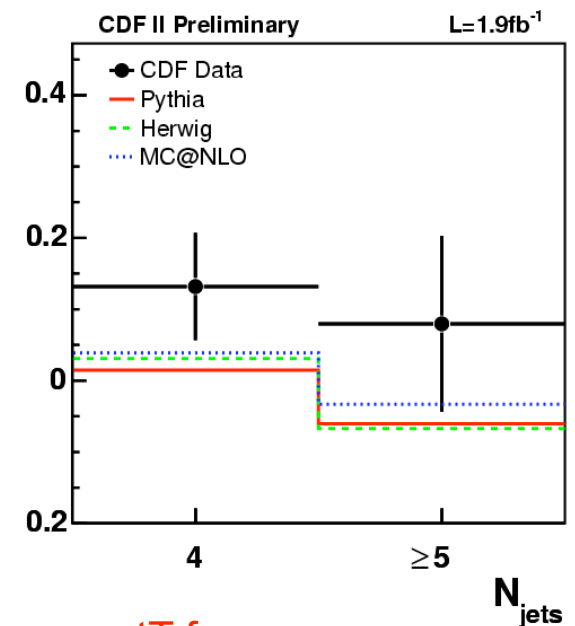
$$A(y) = \frac{N_t(y) - N_{\bar{t}}(y)}{N_t(y) + N_{\bar{t}}(y)}$$



- Interference between LO and box diagrams leads to a positive asymmetry
- Interference between ISR and FSR diagrams leads to a negative asymmetry
- Positive asymmetry wins
- ...but result is larger than NLO expectation, albeit with large errors
- Note that NLO calculation of tTj cross section indicates that asymmetry goes to ~ 0
 - ◆ Dittmaier, Uwer, Weinzierl
 - ◆ arXiv:0810.0452



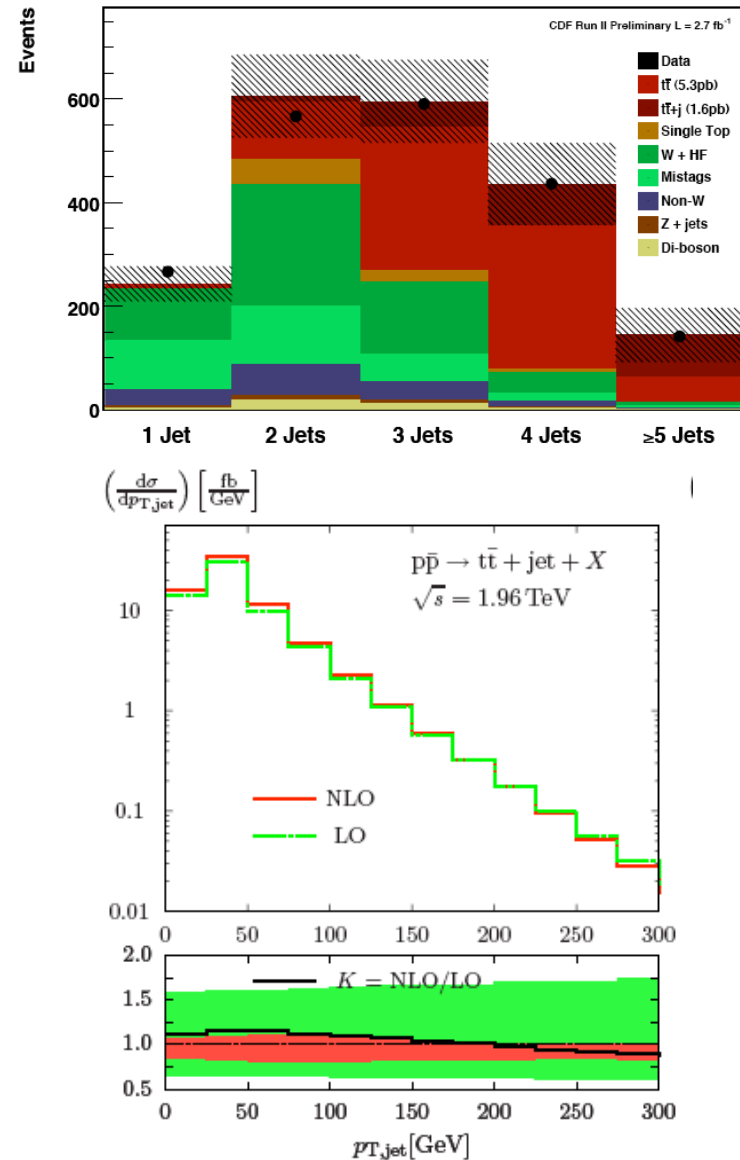
proton-antiproton frame



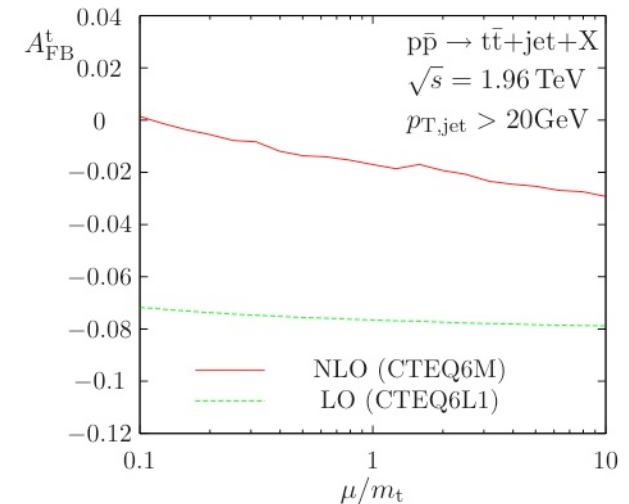
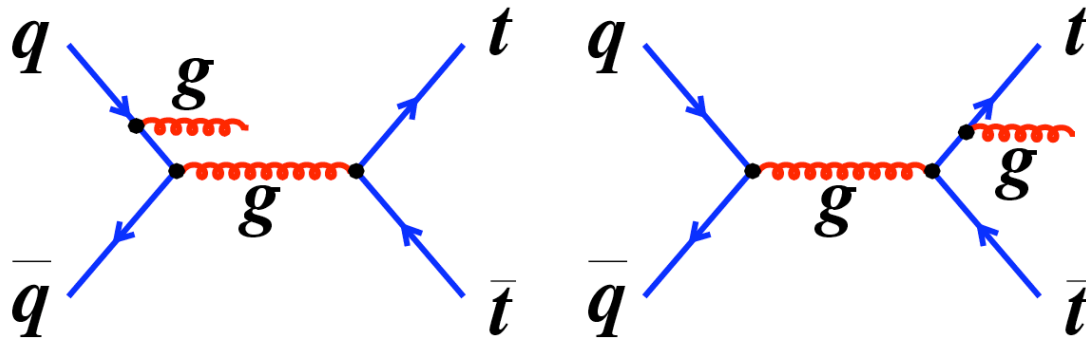
tT frame

tT + jet

- Large integrated luminosity at the Tevatron leads to possibility of precision measurement and comparison to recent NLO calculation
 - ◆ on the order of several hundred events
- Blessed results expected within a few months



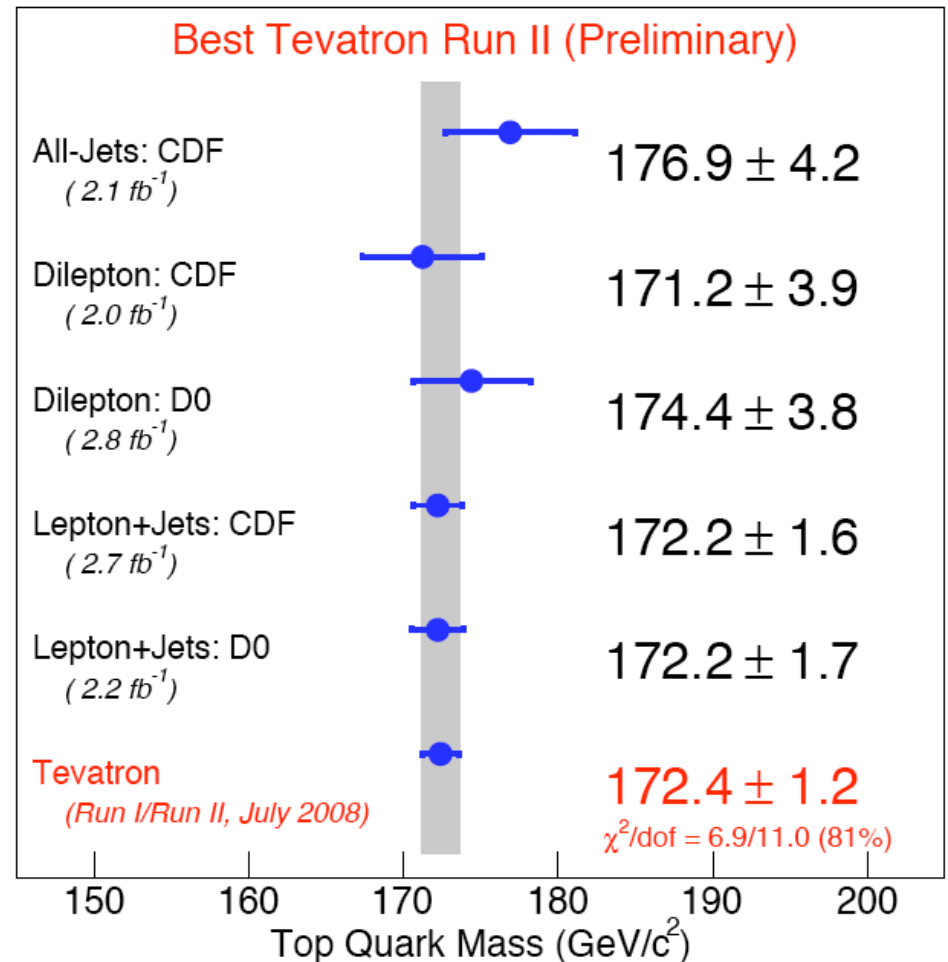
Puzzler



- At LO, the rate for jet production is largest when the acceleration of the color charge is largest
 - ◆ nice physical explanation
- At NLO, that effect is mostly cancelled, due to the loop corrections
 - ◆ why?
 - ◆ Daniel has a prize for anyone who can come up with a good explanation

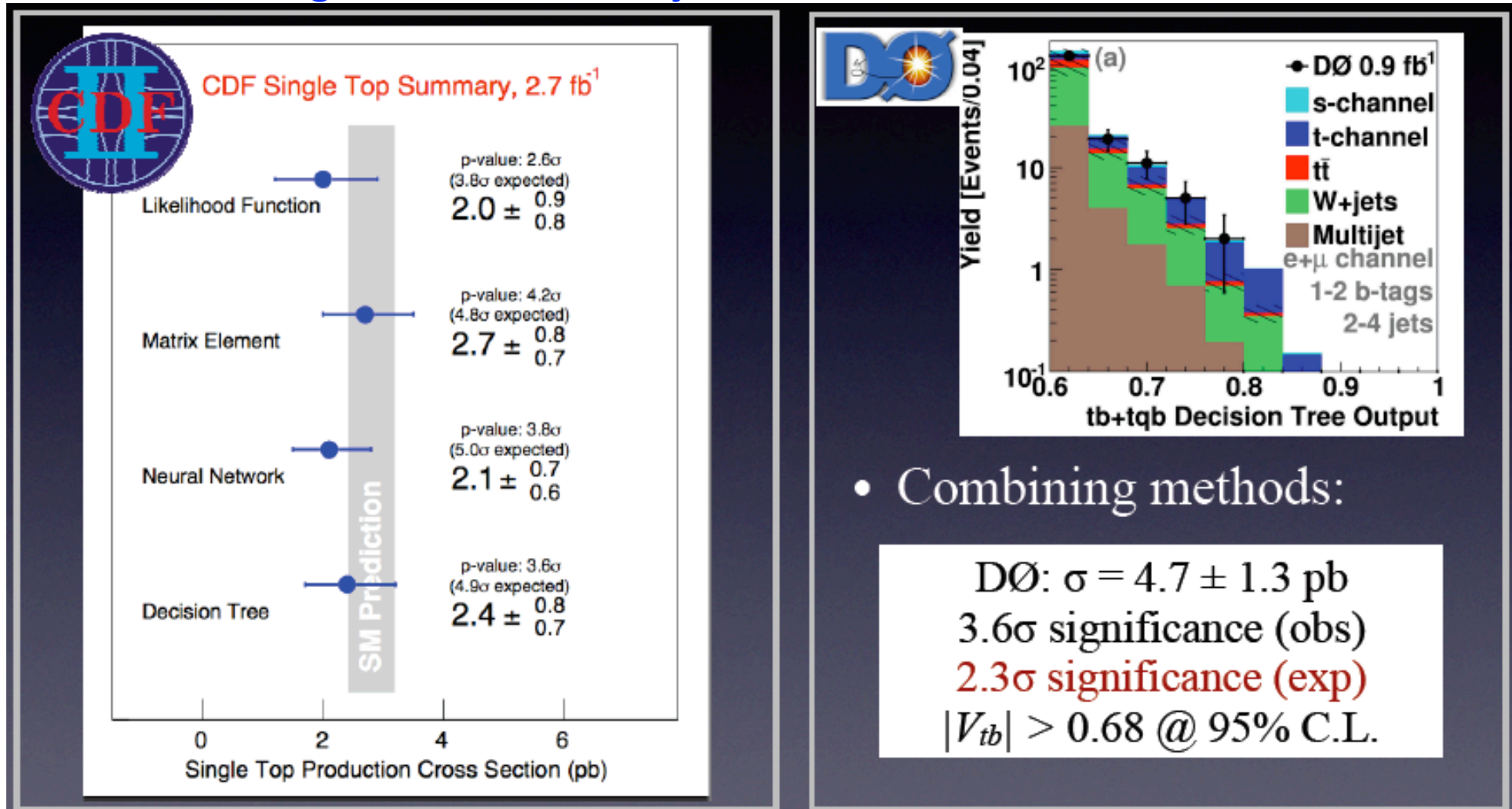
Top mass

- Precision of Tevatron top mass measurement is approaching 1 GeV
 - ◆ it will be a while before the LHC can approach this kind of precision
- Effects previously ignored (like color recombination effects) now need to be seriously considered
 - ◆ Wicke, Skands
 - ◆ arXiv:0807.3248



Single top

- Multivariate discriminants used to find single top candidates
- Closing in on 'discovery'

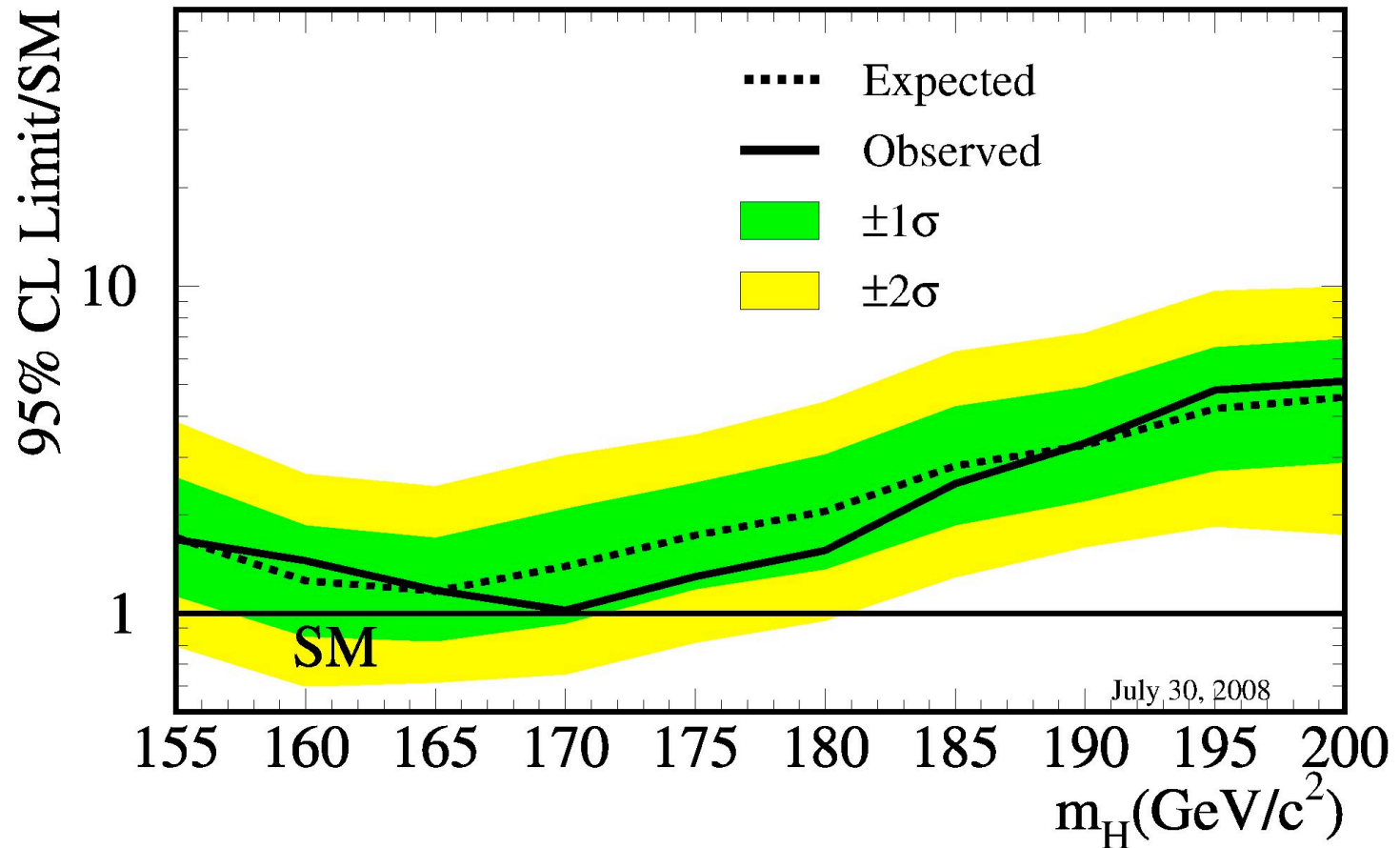


Higgs production

Tevatron Run II Preliminary, $L=3 \text{ fb}^{-1}$

all channels
combined
 3 fb^{-1}

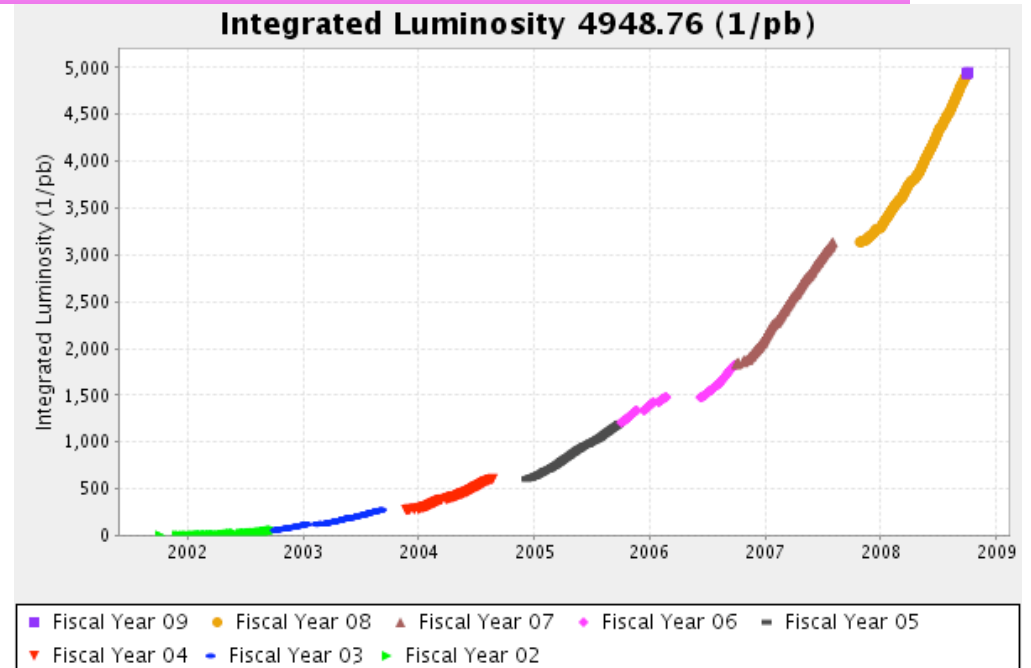
for the first
time a 95% CL
exclusion at
170 GeV



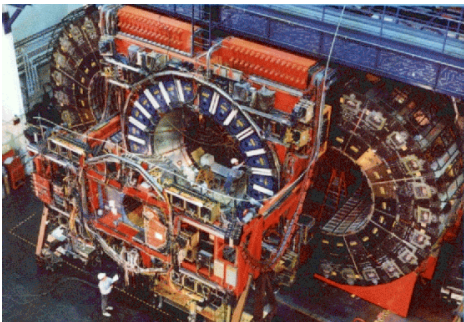
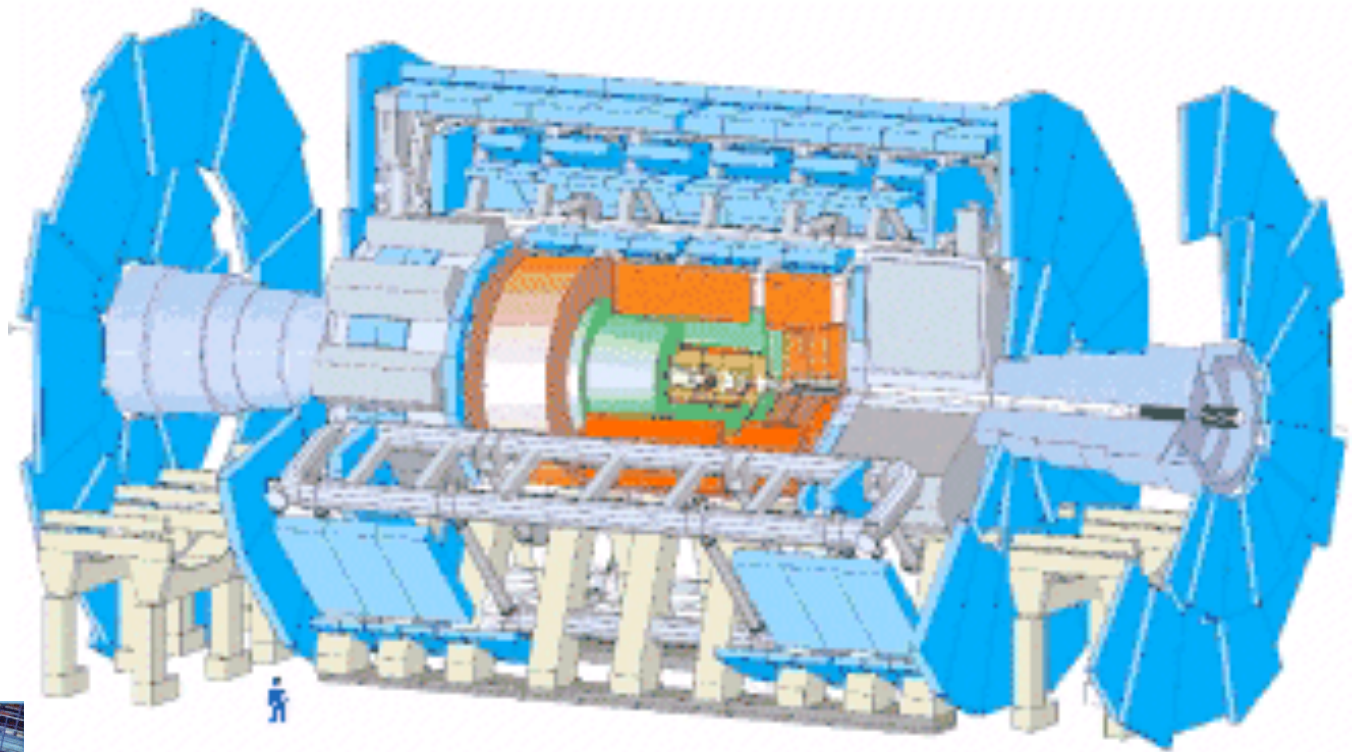
Sensitivity is improving faster than $1/\sqrt{\text{luminosity}}$

Plans

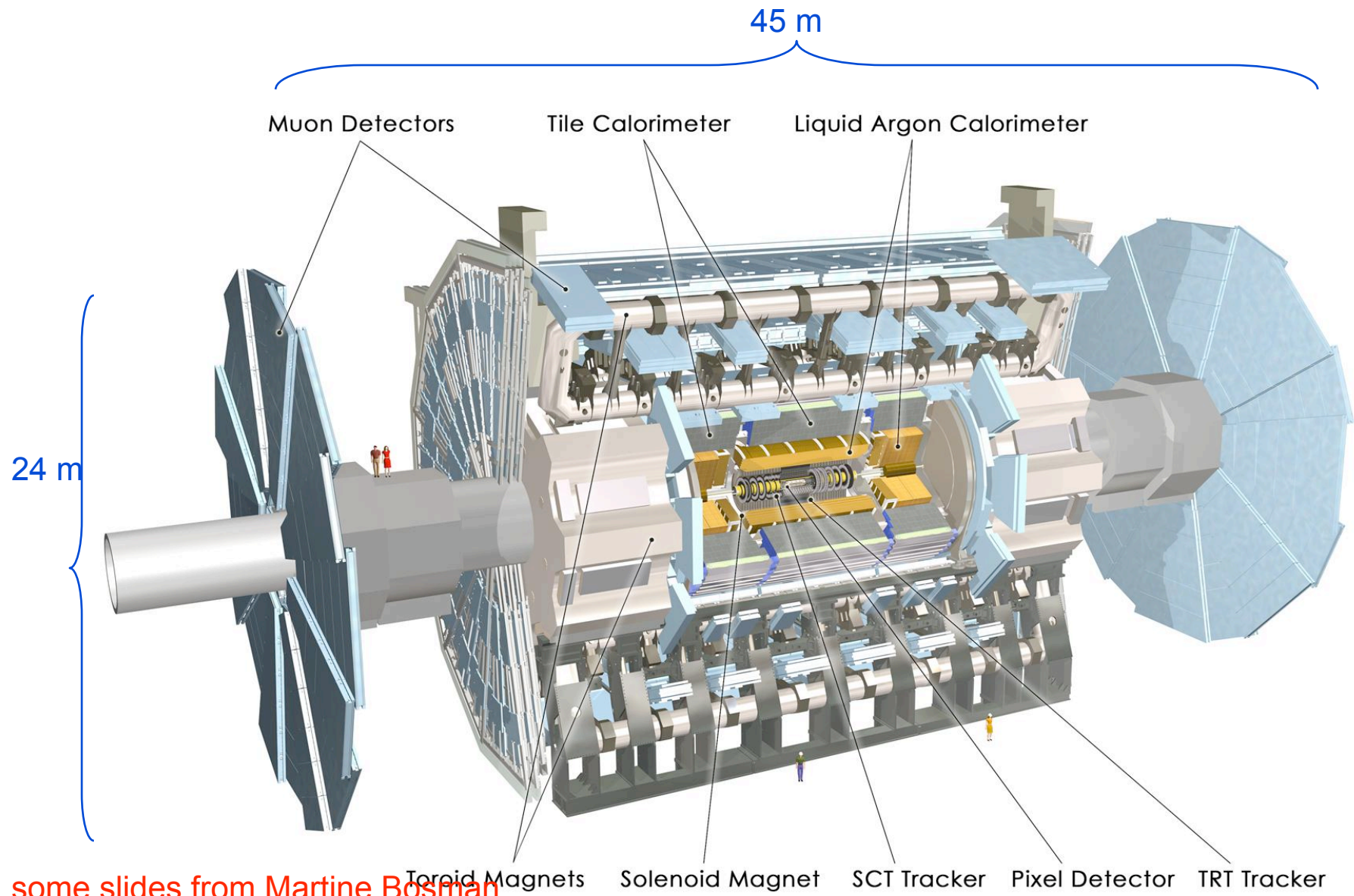
- Tevatron would like to run through 2010
- Perhaps this is more likely now that the LHC startup has slowed
- But it will be a political decision
- But a decision to run may bring some benefits →



CDF->ATLAS

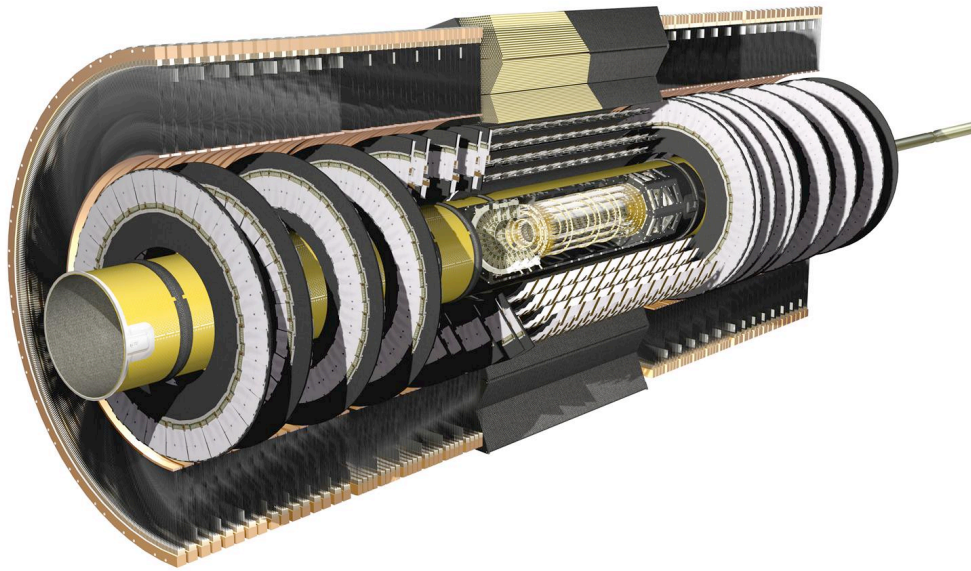


ATLAS



Inner Detector

Tracking $|\eta| < 2.5$ $B=2T$

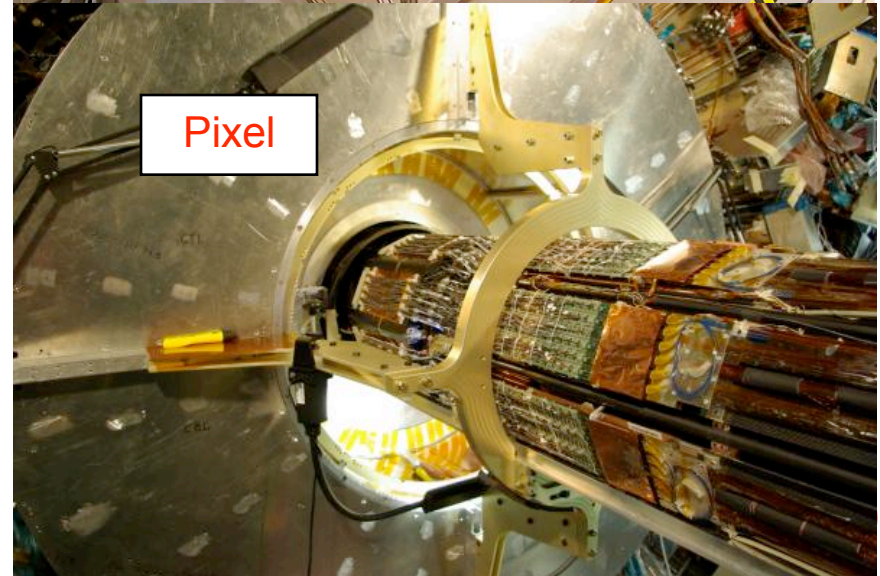
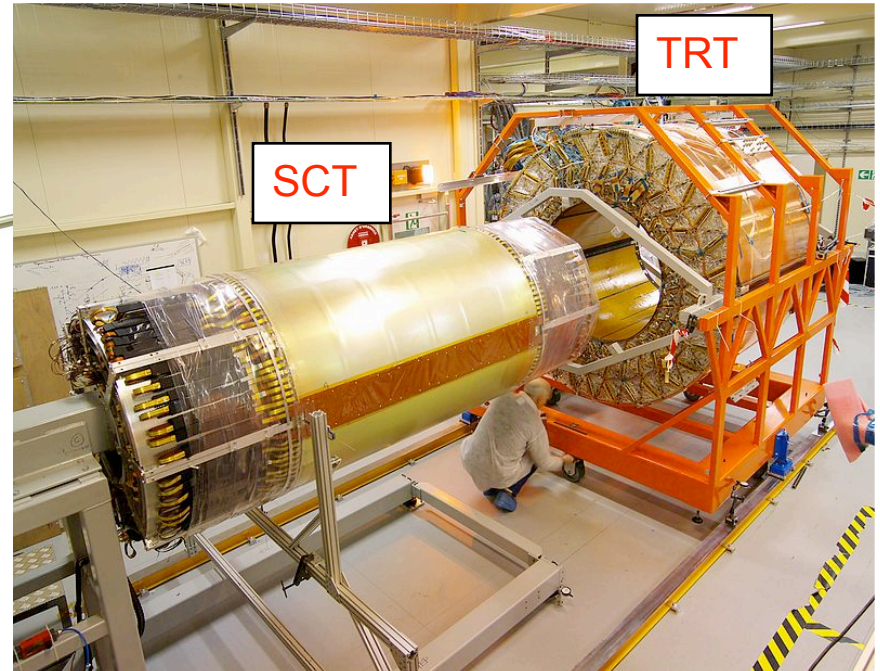


Silicon pixels (**Pixel**): $0.8 \cdot 10^8$ channels

Silicon strips (**SCT**): $6 \cdot 10^6$ channels

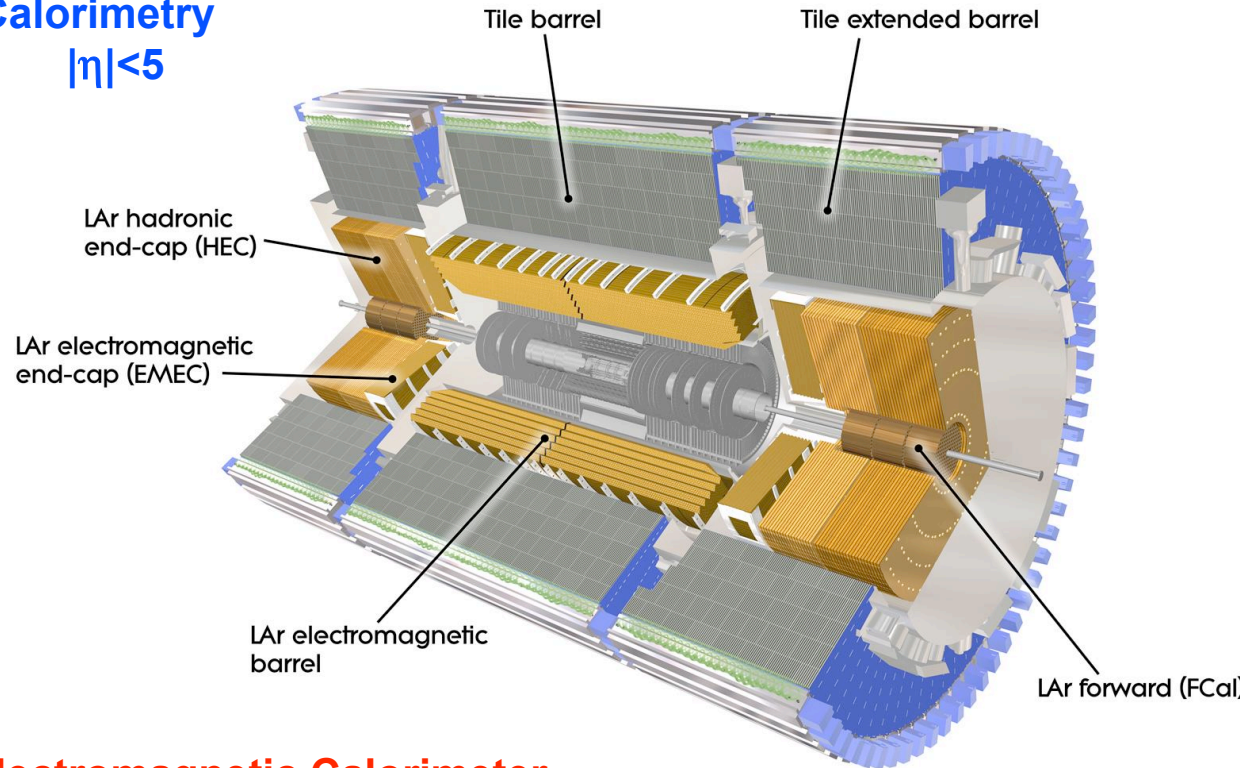
Transition Radiation Tracker (**TRT**):
straw tubes (Xe), $4 \cdot 10^5$ channels
 e/π separation

$$\sigma/p_T \sim 5 \cdot 10^{-4} p_T \oplus 0.01$$



Calorimetry

Calorimetry $|\eta| < 5$



Electromagnetic Calorimeter

barrel, endcap: Pb-LAr

$\sim 10\%/\sqrt{E}$ energy resolution e/γ

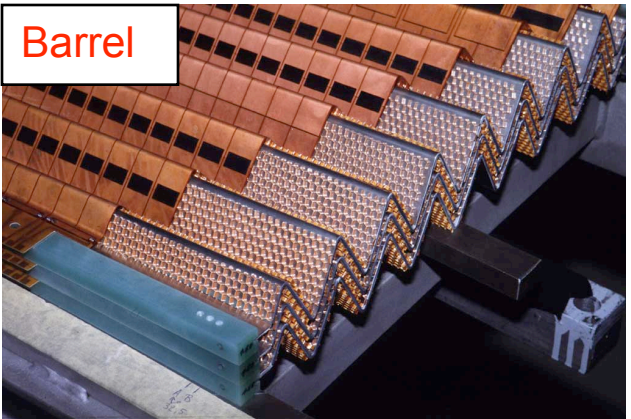
180000 channels: longitudinal segmentation

Hadron Calorimeter

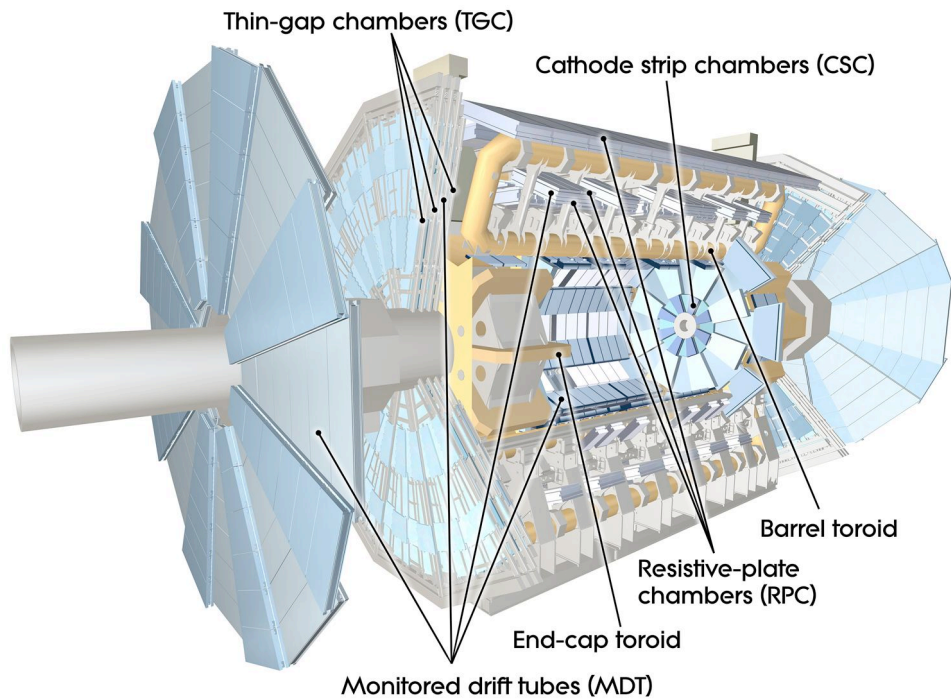
barrel Iron-Tile EC/Fwd Cu/W-LAr (~ 20000 channels)

$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion (10λ)

Trigger for e/γ , jets, Missing E_T



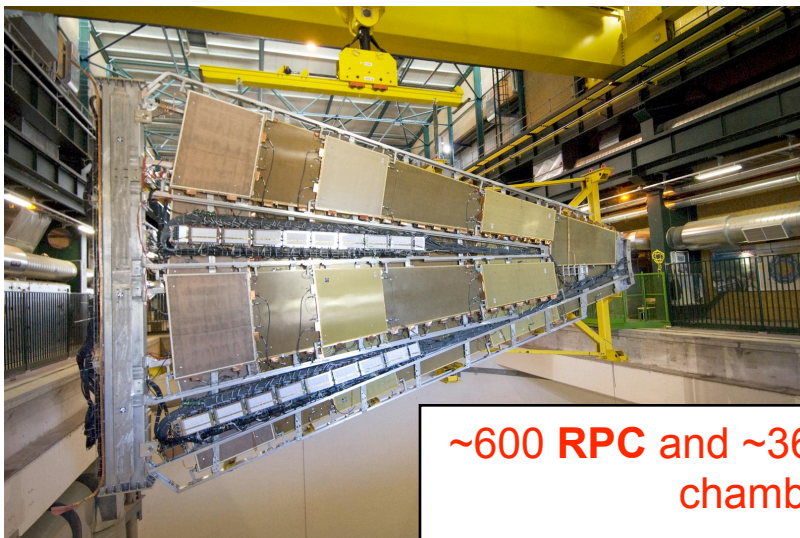
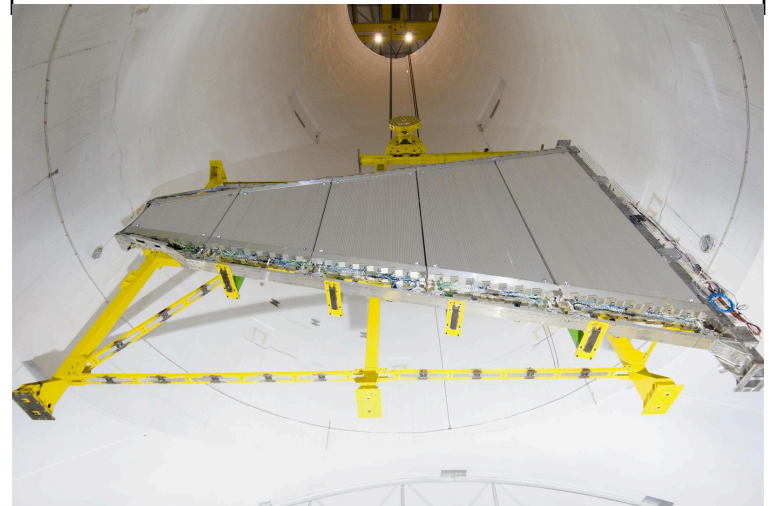
Muon System



Stand-alone momentum resolution $\Delta p_t/p_t < 10\%$ up to 1 TeV

2-6 Tm $|\eta| < 1.3$ 4-8 Tm $1.6 < |\eta| < 2.7$

~1200 **MDT** precision chambers for track reconstruction (+ **CSC**)

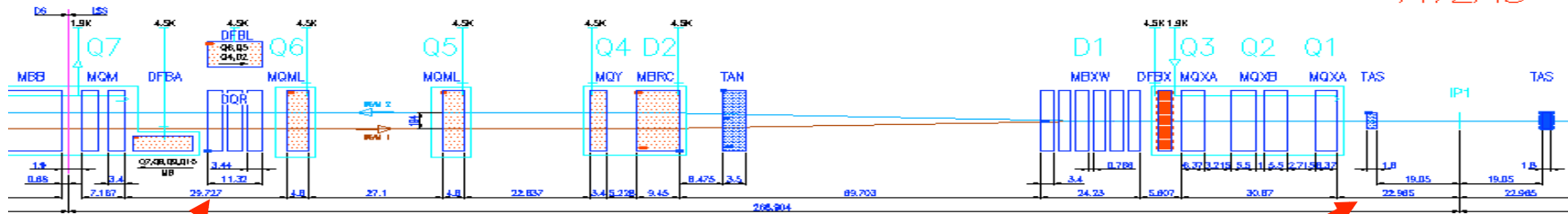


~600 **RPC** and ~3600 **TGC** trigger chambers



Forward Detectors

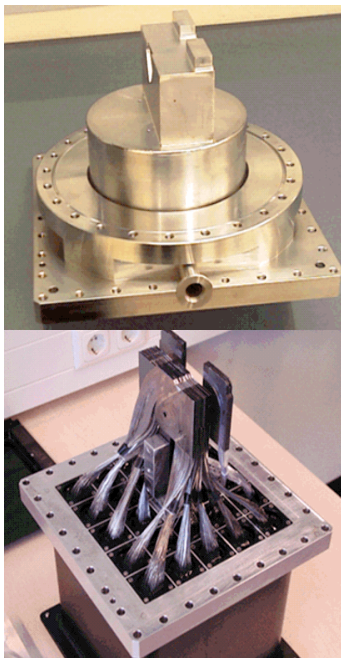
ATLAS



ALFA at 240 m

ZDC at 140 m

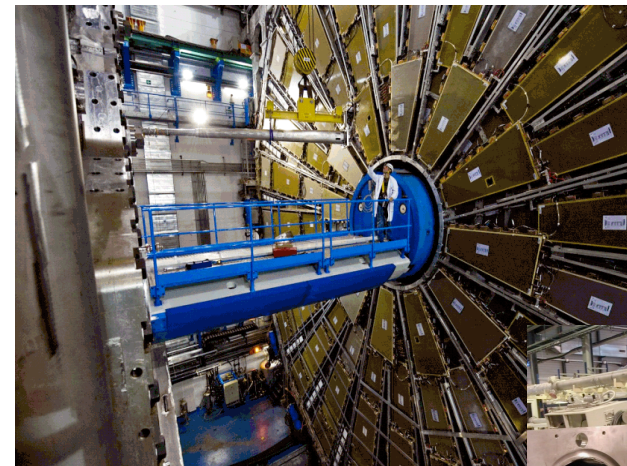
LUCID at 17 m



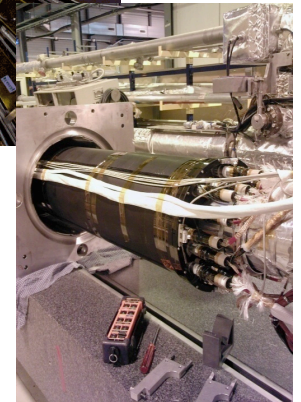
Absolute Luminosity
for ATLAS

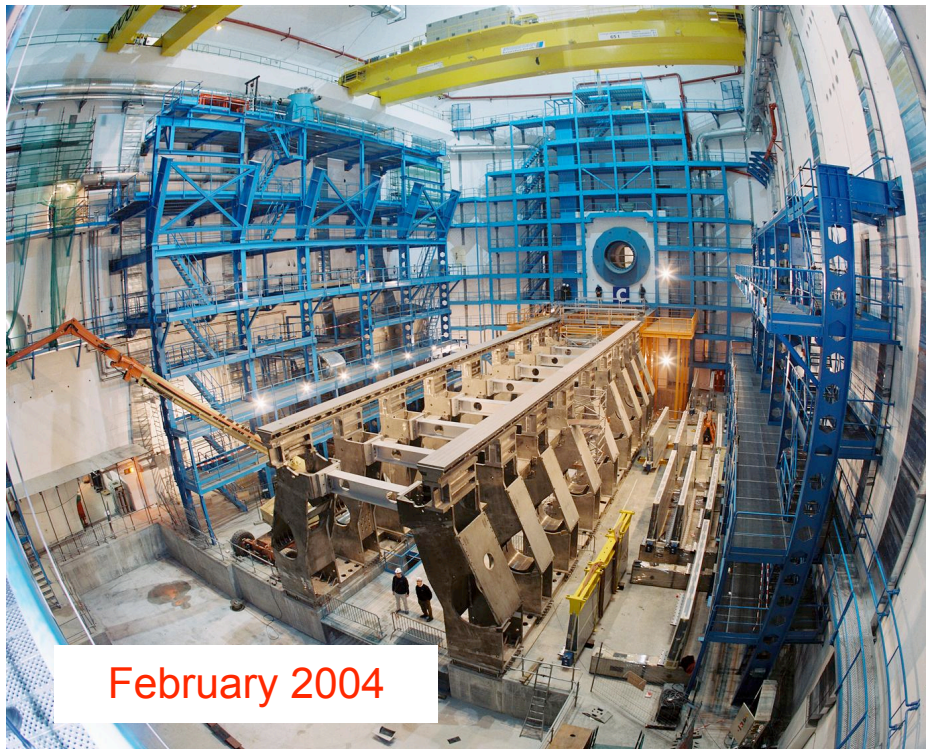


Zero Degree Calorimeter



Luminosity Cerenkov
Integrating Detector

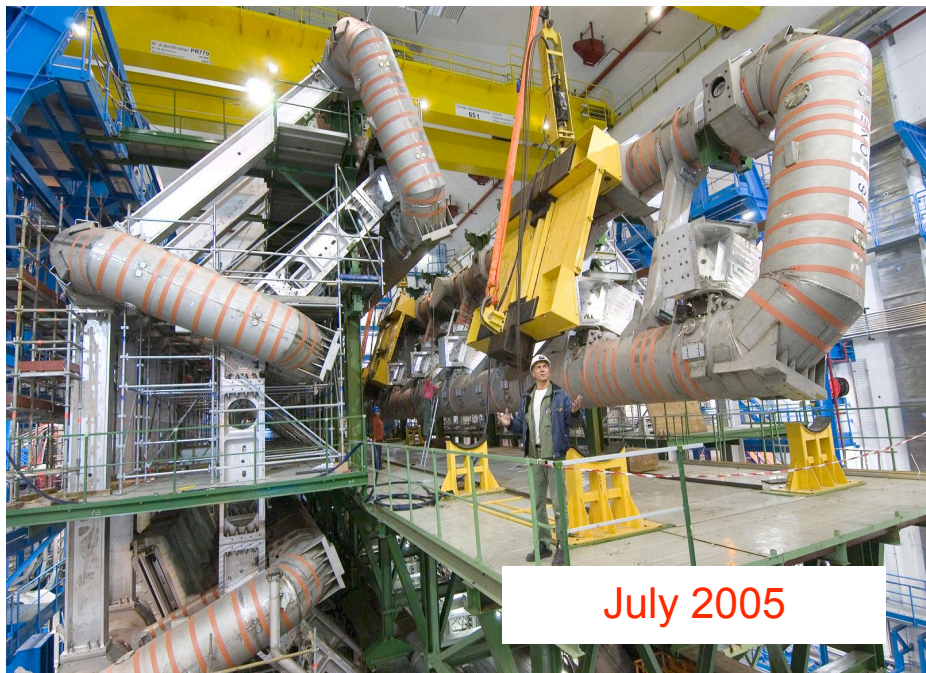




February 2004



October 2004



July 2005

September 2006



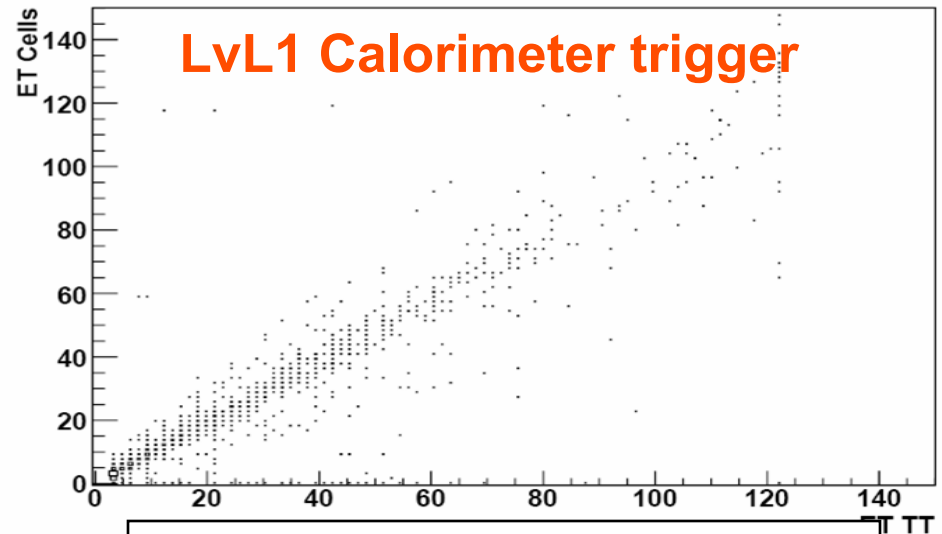
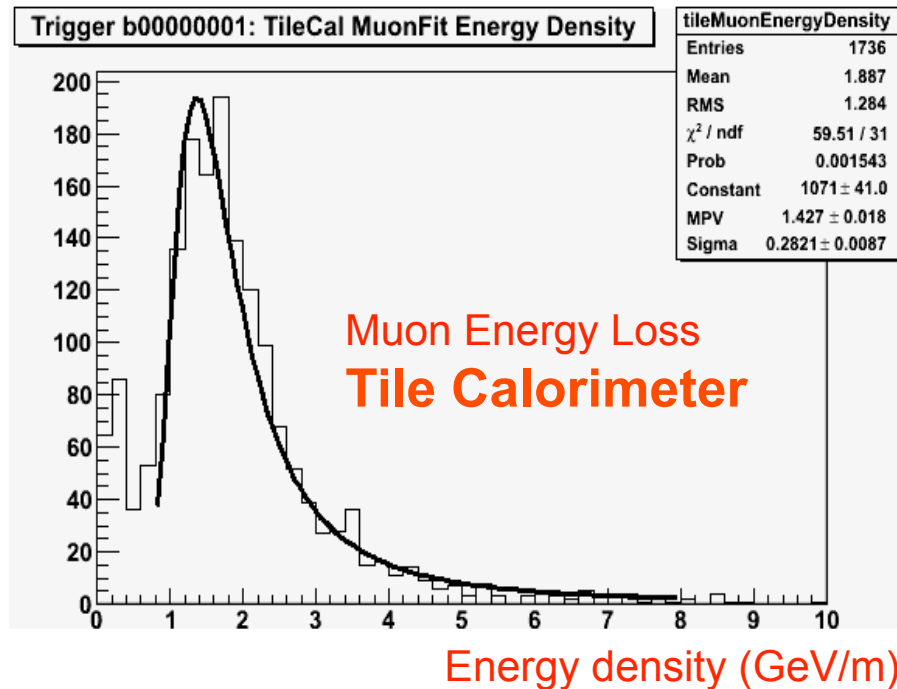
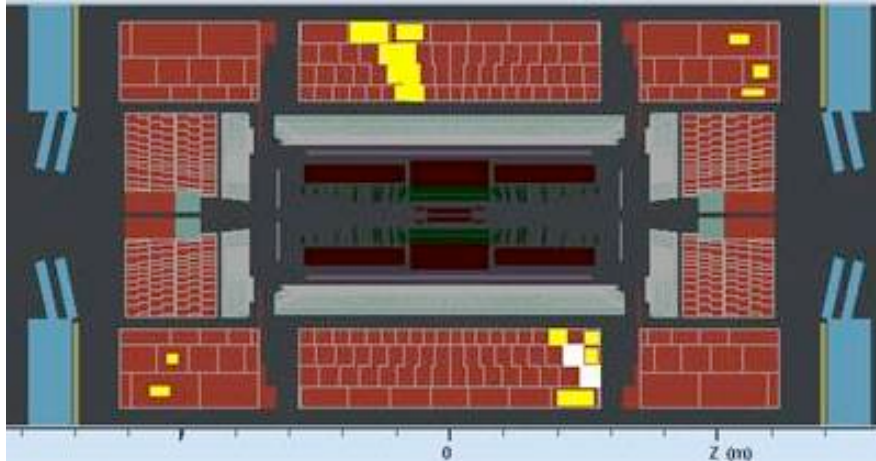
September 2007



February 2008



Lots of commissioning with cosmics

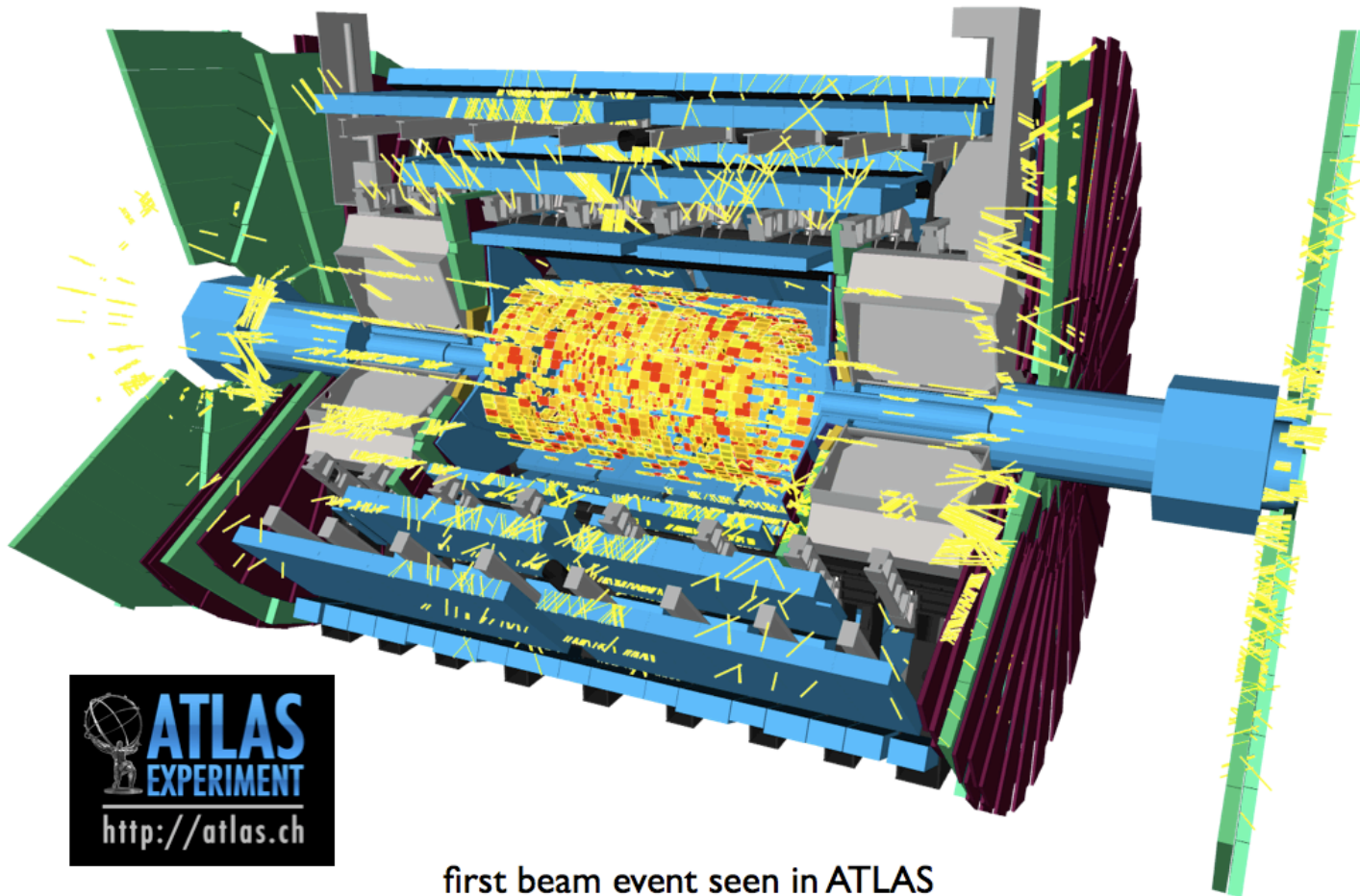


Correlation between
Trigger Tower (Level-1 Calo)
and
Energy (TileCal)

Provides information on:

- Timing
- Energy calibration

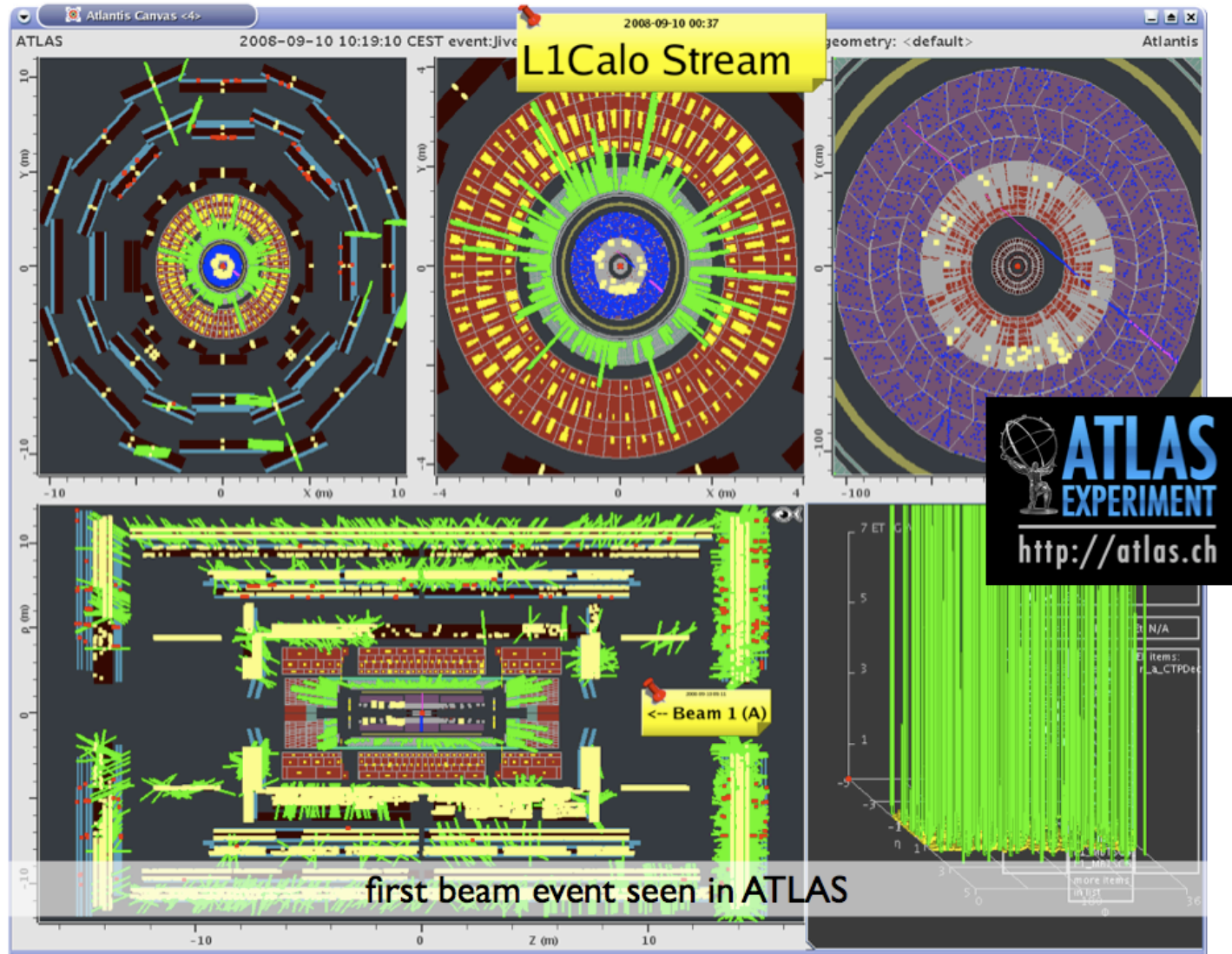
Commissioning with single beam



first beam event seen in ATLAS

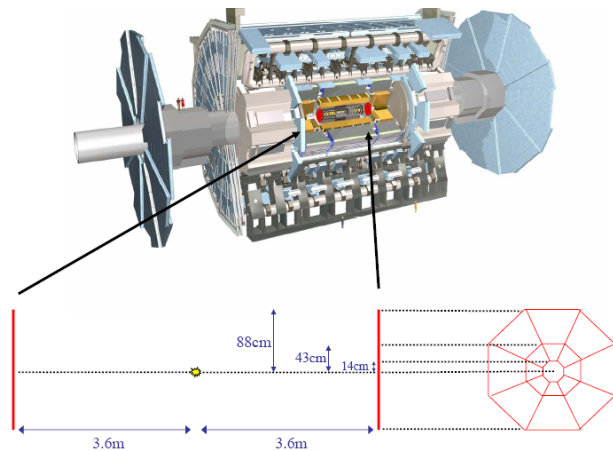
Single beam hitting an upstream collimator, proving that ATLAS can trigger on $1E5$ muons. ~ 1000 TeV in the detector

Other views of first event

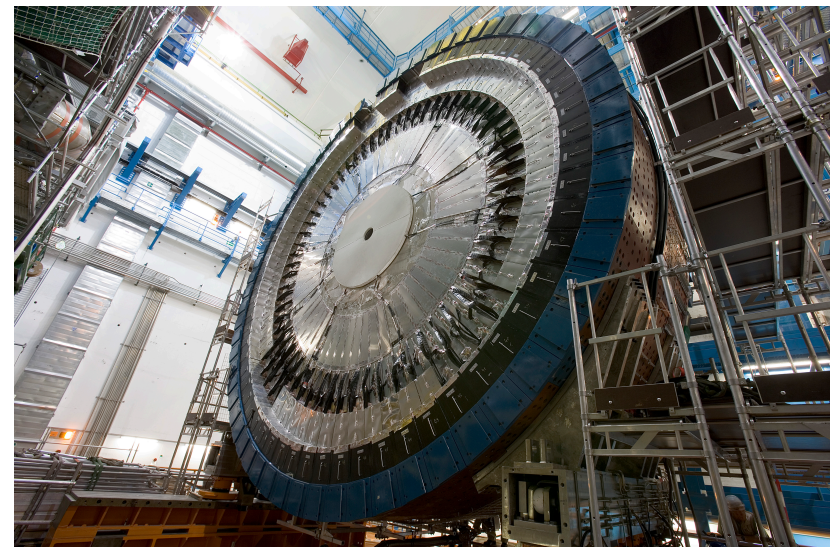
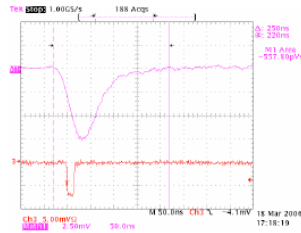


Early triggering in ATLAS

- Beam pickups will indicate which bunches are filled
- Need a fast signal from detector that an interaction has occurred
- This is the role of the MBTS counters
 - ◆ mounted on LAr cryostats and cover an η region from ~ 2 to 3.8

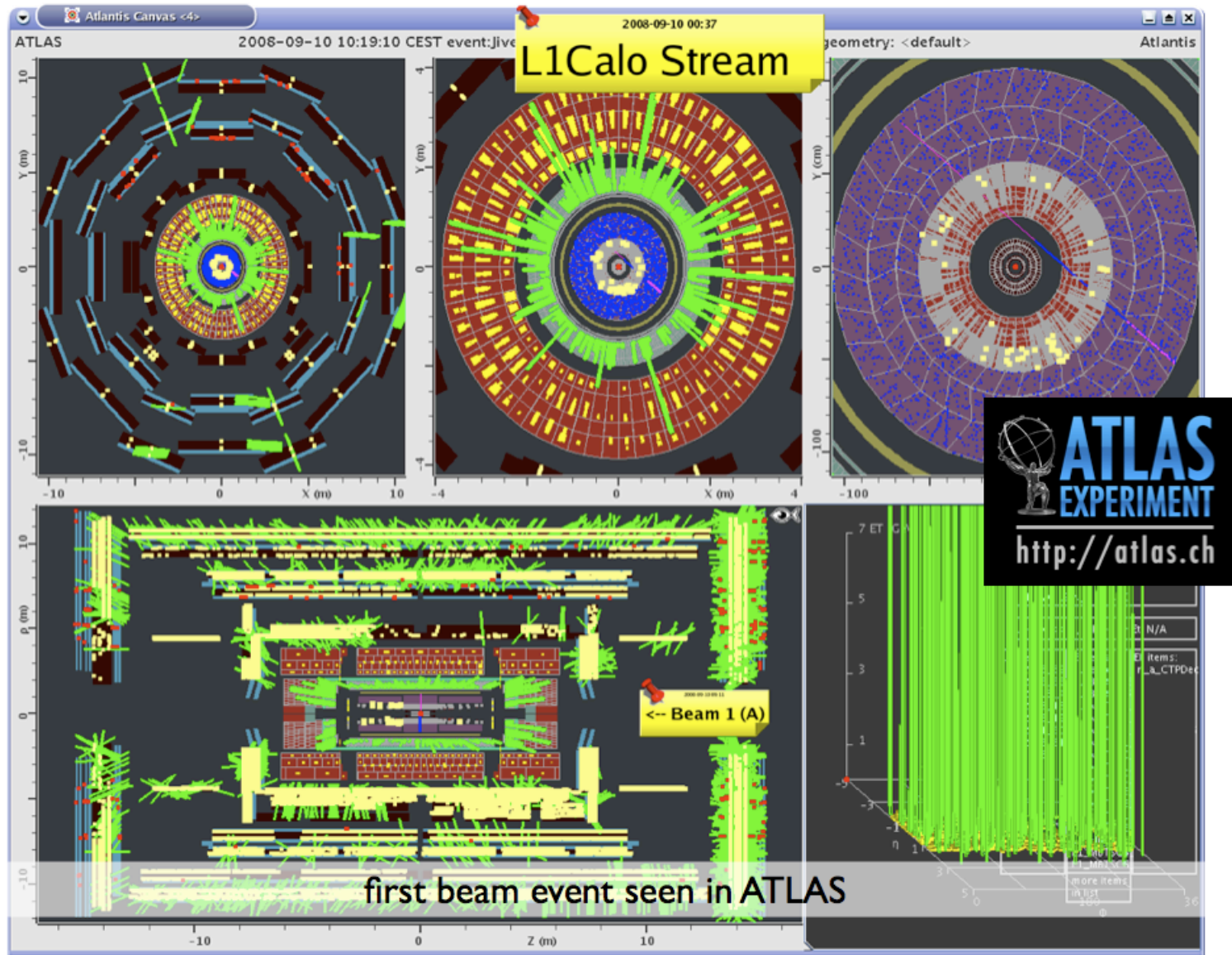


- ◆ 8 segments in ϕ on each side; 2 segments in η



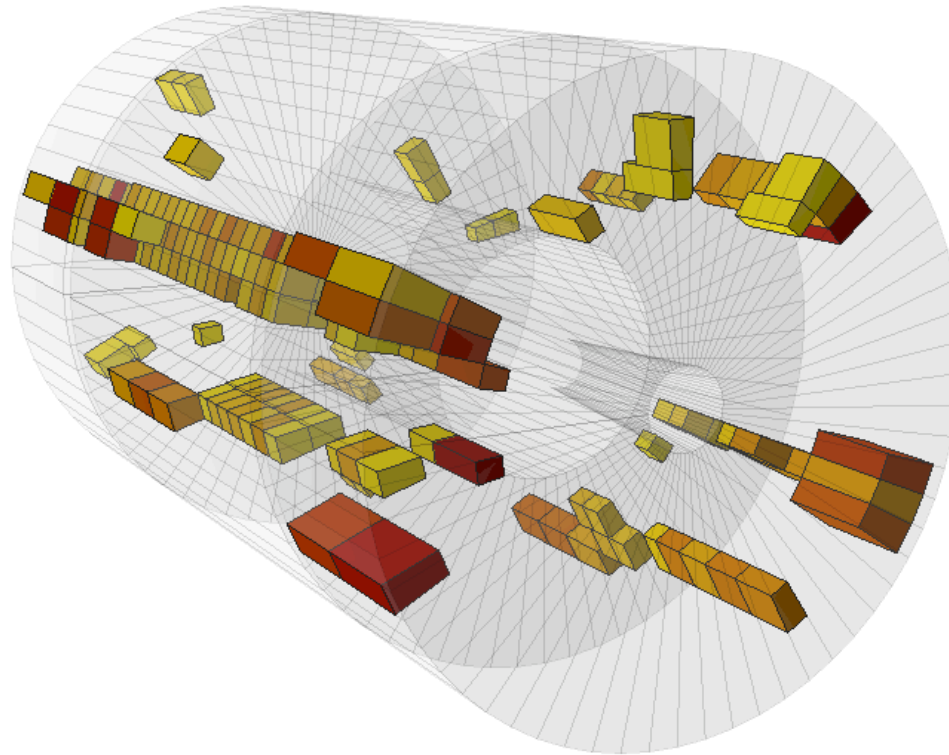
•will be first detector in ATLAS to die (but ok for year)

Another view of first event



It was so useful just to see things moving horizontally

Run 88069 - Event 65720

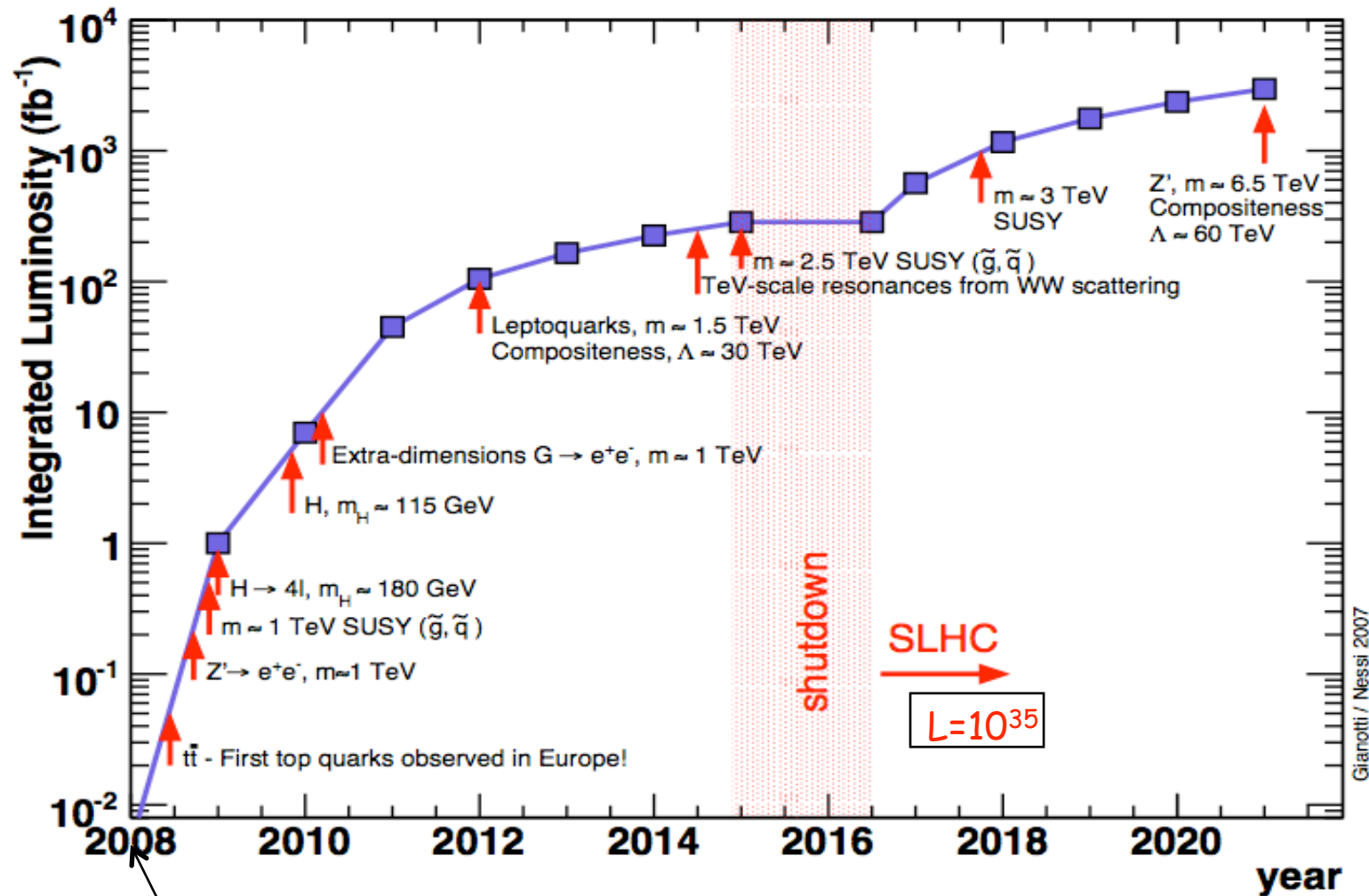


2009

- As you've heard from Guenther, no more beam in 2008
- Turn-on again in April-May of next year at 14 TeV (10 TeV?)
- Meanwhile, we'll continue to analyze our single beam data
- Tune up our analysis software
- And try to fix everything that's broken with the detector
 - ◆ but now with the collision hall re-classified as a radiation environment

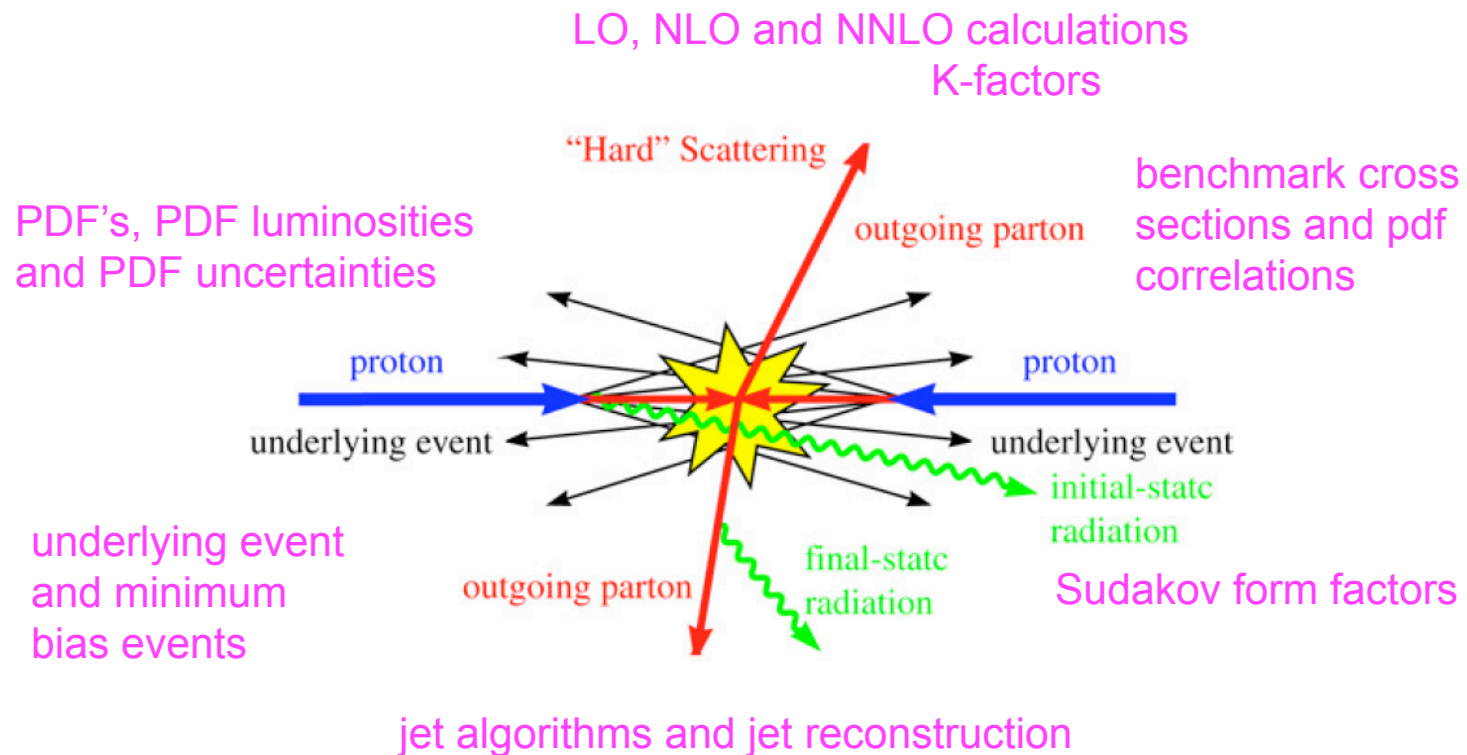
We'll look back on early trouble in 15 years and laugh

LHC vs time: a wild guess ...



...but before looking back

Understanding SM predictions at the LHC



PDF uncertainties at the LHC

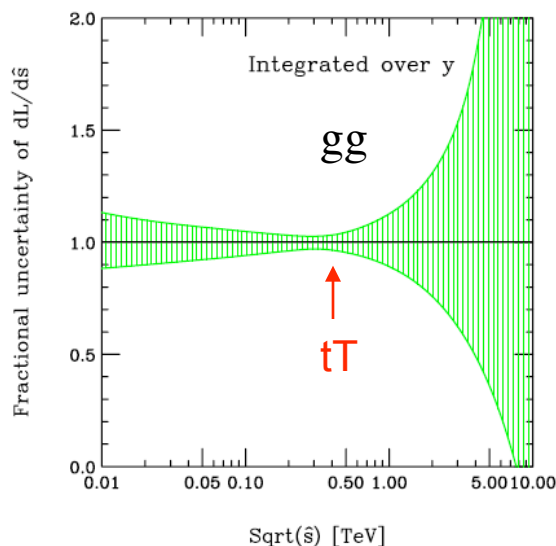


Fig. 4: Fractional uncertainty of gg luminosity integrated over y .

NBIII: tT uncertainty is of the same order as W/Z production

Note that for much of the SM/discovery range, the pdf luminosity uncertainty is small

Need similar level of precision in theory calculations

It will be a while, i.e. not in the first fb^{-1} , before the LHC data starts to constrain pdf's

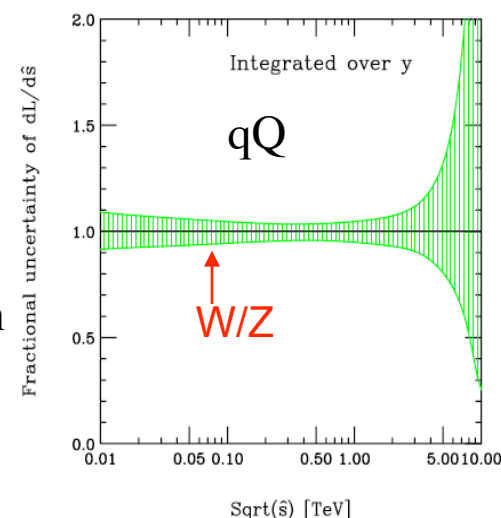


Fig. 7: Fractional uncertainty for Luminosity integrated over y for $d\bar{d} + u\bar{u} + s\bar{s} + c\bar{c} + b\bar{b} + \bar{d}d + \bar{u}u + \bar{s}s + \bar{c}c + \bar{b}b$.

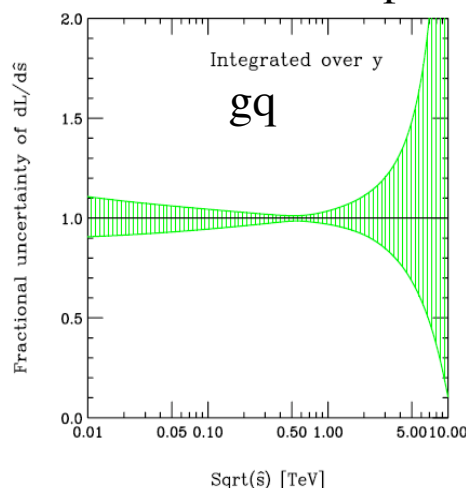


Fig. 6: Fractional uncertainty for Luminosity integrated over y for $g(d + u + s + c + b) + g(\bar{d} + \bar{u} + \bar{s} + \bar{c} + \bar{b}) + (d + u + s + c + b)g + (\bar{d} + \bar{u} + \bar{s} + \bar{c} + \bar{b})g$.

NB I: the errors are determined using the Hessian method for a $\Delta\chi^2$ of 100 using only experimental uncertainties, i.e. no theory uncertainties

NB II: the pdf uncertainties for W/Z cross sections are not the smallest

Ratios:LHC to Tevatron pdf luminosities

- Processes that depend on qQ initial states (e.g. chargino pair production) have small enhancements
- Most backgrounds have gg or gq initial states and thus large enhancement factors (500 for W + 4 jets for example, which is primarily gq) at the LHC
- W+4 jets is a background to tT production both at the Tevatron and at the LHC
- tT production at the Tevatron is largely through a qQ initial states and so qQ->tT has an enhancement factor at the LHC of ~10
- Luckily tT has a gg initial state as well as qQ so total enhancement at the LHC is a factor of 100
 - but increased W + jets background means that a higher jet cut is necessary at the LHC
 - known known: jet cuts have to be higher at LHC than at Tevatron

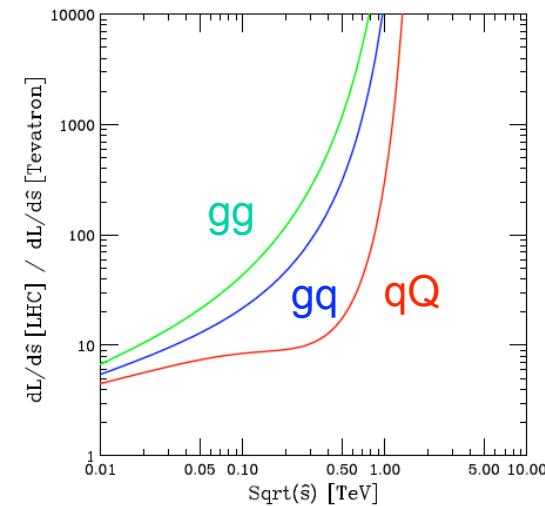


Figure 11. The ratio of parton-parton luminosity $\left[\frac{1}{s} \frac{dL}{ds}\right]$ in pb integrated over y at the LHC and Tevatron. Green= gg (top), Blue= $g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$ (middle), Red= $d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$ (bottom).

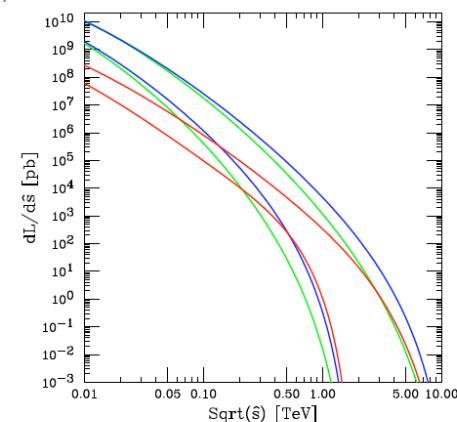


Figure 10. The parton-parton luminosity $\left[\frac{1}{s} \frac{dL}{ds}\right]$ in pb integrated over y . Green= gg , Blue= $g(d+u+s+c+b)+g(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})+(d+u+s+c+b)g+(\bar{d}+\bar{u}+\bar{s}+\bar{c}+\bar{b})g$, Red= $d\bar{d}+u\bar{u}+s\bar{s}+c\bar{c}+b\bar{b}+\bar{d}d+\bar{u}u+\bar{s}s+\bar{c}c+\bar{b}b$. The top family of curves are for the LHC and the bottom for the Tevatron.

Known known: the LHC will be a very *jetty* place

- Total cross sections for $t\bar{t}$ and Higgs production saturated by $t\bar{t}$ (Higgs) + jet production for jet p_T values of order 10-20 GeV/c
- $\sigma_{W+3 \text{ jets}} > \sigma_{W+2 \text{ jets}}$

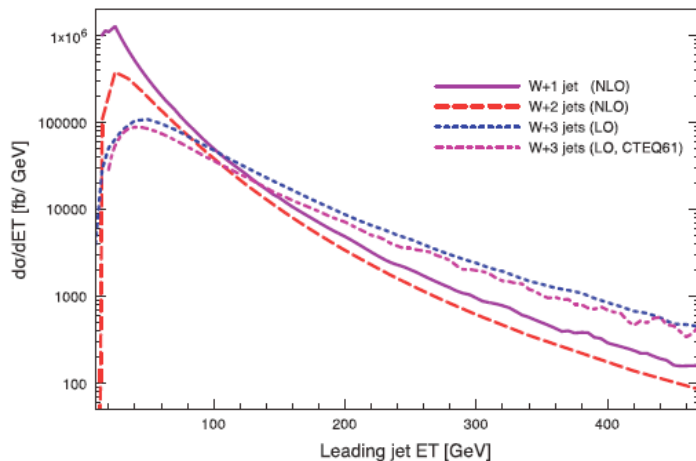


Figure 91. Predictions for the production of $W + \geq 1, 2, 3$ jets at the LHC shown as a function of the transverse energy of the lead jet. A cut of 20 GeV has been placed on the other jets in the prediction.

- Indication that can expect interesting events at LHC to be very *jetty* (especially from gg initial states)

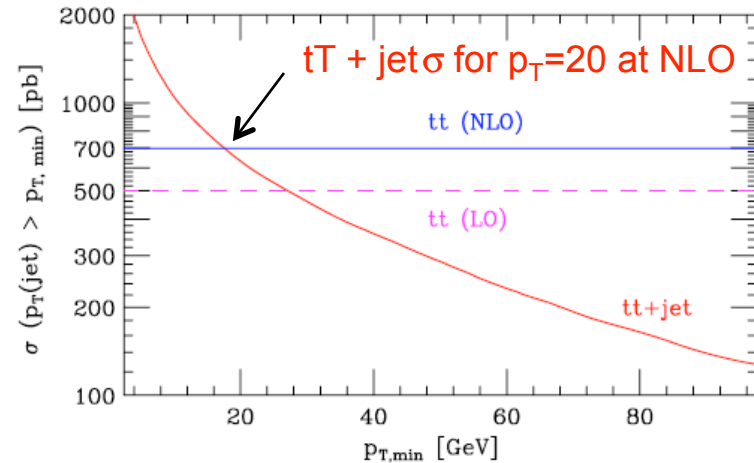


Figure 95. The dependence of the LO $t\bar{t}$ +jet cross section on the jet-defining parameter $p_{T,min}$, together with the top pair production cross sections at LO and NLO.

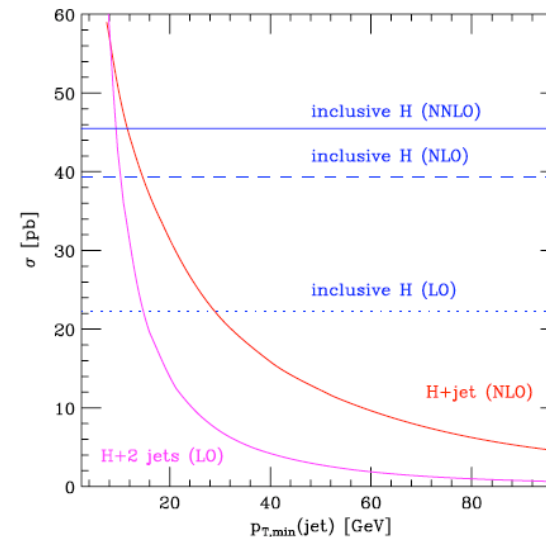
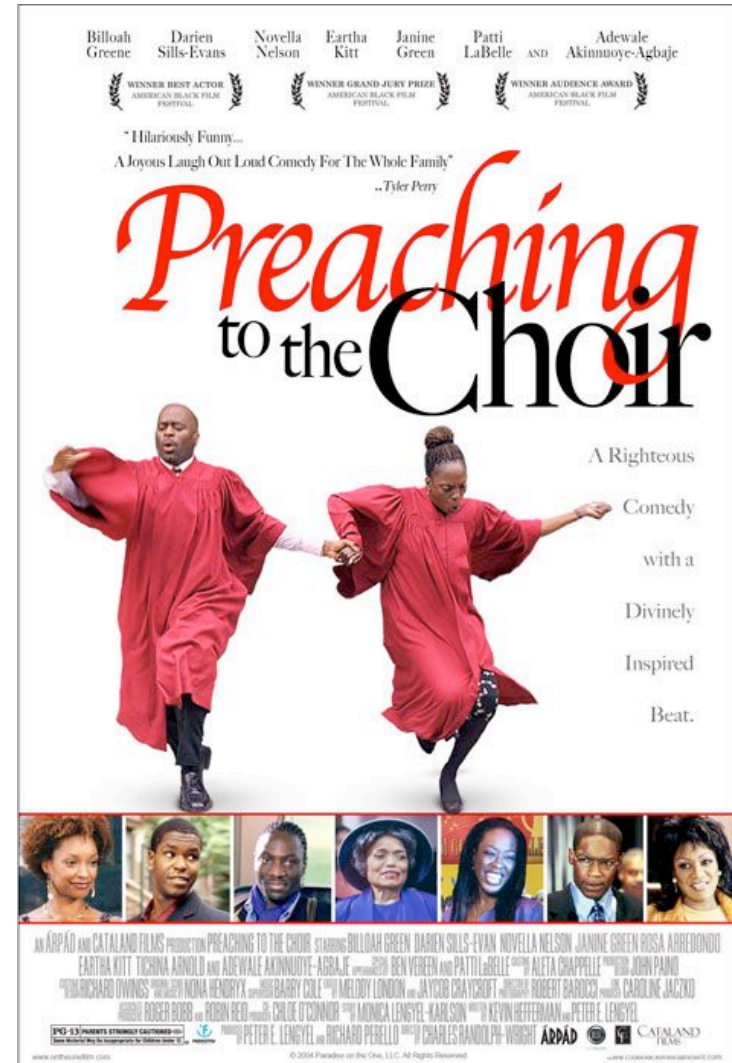


Figure 100. The dependence of the LO $t\bar{t}$ +jet cross section on the jet-defining parameter $p_{T,min}$, together with the top pair production cross sections at LO and NLO.

NLO corrections

- NLO is the first order for which the normalization, and sometimes the shape, is believable
- NLO is necessary for precision comparisons of data to theory
 - ◆ for this talk, this is what is known as preaching to the choir
- Sometimes backgrounds to new physics can be extrapolated from non-signal regions, but this is difficult to do for low cross section final states and/or final states where a clear separation of a signal and background region is difficult



NLO corrections

Sometimes it is useful to define a K-factor (NLO/LO). Note the value of the K-factor depends critically on its definition. K-factors at LHC (mostly) similar to those at Tevatron.

Process	Typical scales		Tevatron K -factor			LHC K -factor		
	μ_0	μ_1	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
$W+1\text{jet}$	m_W	p_T^{jet}	1.42	1.20	1.43	1.21	1.32	1.42
$W+2\text{jets}$	m_W	p_T^{jet}	1.16	0.91	1.29	0.89	0.88	1.10
$WW+\text{jet}$	m_W	$2m_W$	1.19	1.37	1.26	1.33	1.40	1.42
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$t\bar{t}+1\text{jet}$	m_t	$2m_t$	1.13	1.43	1.37	0.97	1.29	1.10
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs	m_H	p_T^{jet}	2.33	–	2.33	1.72	–	2.32
Higgs via VBF	m_H	p_T^{jet}	1.07	0.97	1.07	1.23	1.34	1.09
Higgs+1jet	m_H	p_T^{jet}	2.02	–	2.13	1.47	–	1.90
Higgs+2jets	m_H	p_T^{jet}	–	–	–	1.15	–	–

K-factors may differ from unity because of new subprocesses/contributions at higher order and/or differences between LO and NLO pdf's

Table 2: K -factors for various processes at the Tevatron and the LHC calculated using a selection of input parameters. In all cases, the CTEQ6M PDF set is used at NLO. \mathcal{K} uses the CTEQ6L1 set at leading order, whilst \mathcal{K}' uses the same set, CTEQ6M, as at NLO. For most of the processes listed, jets satisfy the requirements $p_T > 15 \text{ GeV}/c$ and $|\eta| < 2.5$ (5.0) at the Tevatron (LHC). For Higgs+1,2jets, a jet cut of 40 GeV/c and $|\eta| < 4.5$ has been applied. A cut of $p_T^{\text{jet}} > 20 \text{ GeV}/c$ has been applied for the $t\bar{t}+\text{jet}$ process, and a cut of $p_T^{\text{jet}} > 50 \text{ GeV}/c$ for $WW+\text{jet}$. In the $W(\text{Higgs})+2\text{jets}$ process the jets are separated by $\Delta R > 0.52$, whilst the VBF calculations are performed for a Higgs boson of mass 120 GeV. In each case the value of the K -factor is compared at two often-used scale choices, where the scale indicated is used for both renormalization and factorization scales.

Les Houches 2007

NLO calculation priority list from Les Houches 2005: theory benchmarks

G. Heinrich and J. Huston

process ($V \in \{Z, W, \gamma\}$)	relevant for
1. $pp \rightarrow VV + \text{jet}$	$t\bar{t}H$, new physics
2. $pp \rightarrow H + 2 \text{ jets}$	H production by vector boson fusion (VBF)
3. $pp \rightarrow t\bar{t}b\bar{b}$	$t\bar{t}H$
4. $pp \rightarrow t\bar{t} + 2 \text{ jets}$	$t\bar{t}H$
5. $pp \rightarrow VVb\bar{b}$	VBF $\rightarrow H \rightarrow VV$, $t\bar{t}H$, new physics
6. $pp \rightarrow VV + 2 \text{ jets}$	VBF $\rightarrow H \rightarrow VV$
7. $pp \rightarrow V + 3 \text{ jets}$	various new physics signatures
8. $pp \rightarrow VVV$	SUSY trilepton

*
*
+

+
*

Table 2. The wishlist of processes for which a NLO calculation is both desired and feasible in the near future.

pp->bBbB
pp->4 jets
gg->W*W*

added in 2007

*completed
since
list
+people are
working

- $pp \rightarrow VV + \text{jet}$: One of the most promising channels for Higgs production in the low mass range is through the $H \rightarrow WW^*$ channel, with the W's decaying semi-leptonically. It is useful to look both in the $H \rightarrow WW$ exclusive channel, along with the $H \rightarrow WW + \text{jet}$ channel. The calculation of $pp \rightarrow WW + \text{jet}$ will be especially important in understanding the background to the latter.
- $pp \rightarrow H + 2 \text{ jets}$: A measurement of vector boson fusion (VBF) production of the Higgs boson will allow the determination of the Higgs coupling to vector bosons. One of the key signatures for this process is the presence of forward-backward tagging jets. Thus, QCD production of $H + 2 \text{ jets}$ must be understood, especially as the rates for the two are comparable in the kinematic regions of interest.
- $pp \rightarrow t\bar{t}b\bar{b}$ and $pp \rightarrow t\bar{t} + 2 \text{ jets}$: Both of these processes serve as background to $t\bar{t}H$, where the Higgs decays into a $b\bar{b}$ pair. The rate for $t\bar{t}jj$ is much greater than that for $t\bar{t}b\bar{b}$ and thus, even if 3 b -tags are required, there may be a significant chance for the heavy flavour mistag of a $t\bar{t}jj$ event to contribute to the background.
- $pp \rightarrow VVb\bar{b}$: Such a signature serves as non-resonant background to $t\bar{t}$ production as well as to possible new physics.
- $pp \rightarrow VV + 2 \text{ jets}$: The process serves as a background to VBF production of Higgs.
- $pp \rightarrow V + 3 \text{ jets}$: The process serves as background for $t\bar{t}$ production where one of the jets may not be reconstructed, as well as for various new physics signatures involving leptons, jets and missing transverse momentum.
- $pp \rightarrow VVV$: The process serves as a background for various new physics subprocesses such as SUSY tri-lepton production.

²³ Process 2 has been calculated since the first version of this list was formulated [138].

What about time lag in going from availability of matrix elements to having a parton level Monte Carlo available? See e.g. $H + 2 \text{ jets}$. Other processes are going to be just as complex. What about other processes for which we are theorist/time-limited? What about codes *too complex* for non-experts to run? See CTEQ4LHC

Go back to K-factor table

- Some rules-of-thumb
- NLO corrections are larger for processes in which there is a great deal of color annihilation
 - $gg \rightarrow \text{Higgs}$
 - $gg \rightarrow \gamma\gamma$
 - $K(gg \rightarrow t\bar{t}) > K(q\bar{q} \rightarrow t\bar{t})$
- NLO corrections decrease as more final-state legs are added
 - $K(gg \rightarrow \text{Higgs} + 2 \text{ jets}) < K(gg \rightarrow \text{Higgs} + 1 \text{ jet}) < K(gg \rightarrow \text{Higgs})$
 - unless can access new initial state gluon channel
- Can we generalize for uncalculated HO processes?
 - so expect K factor for $W + 3 \text{ jets}$ or $\text{Higgs} + 3 \text{ jets}$ to be reasonably close to 1

Table 1. K -factors for various processes at the Tevatron and the LHC, calculated using a selection of input parameters. In all cases, the CTEQ6M PDF set is used at NLO. \mathcal{K} uses the CTEQ6L1 set at leading order, whilst \mathcal{K}' uses the same set, CTEQ6M, as at NLO. Jets satisfy the requirements $p_T > 15$ GeV and $|\eta| < 2.5$ (5.0) at the Tevatron (LHC). In the $W + 2$ jet process the jets are separated by $\Delta R > 0.52$, whilst the weak boson fusion (WBF) calculations are performed for a Higgs of mass 120 GeV.

Process	Typical scales		Tevatron K-factor			LHC K-factor		
	μ_0	μ_1	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
$W + 1 \text{ jet}$	m_W	$\langle p_T^{\text{jet}} \rangle$	1.42	1.20	1.43	1.21	1.32	1.42
$W + 2 \text{ jets}$	m_W	$\langle p_T^{\text{jet}} \rangle$	1.16	0.91	1.29	0.89	0.88	1.10
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs via WBF	m_H	$\langle p_T^{\text{jet}} \rangle$	1.07	0.97	1.07	1.23	1.34	1.09

Casimir for biggest color representation final state can be in

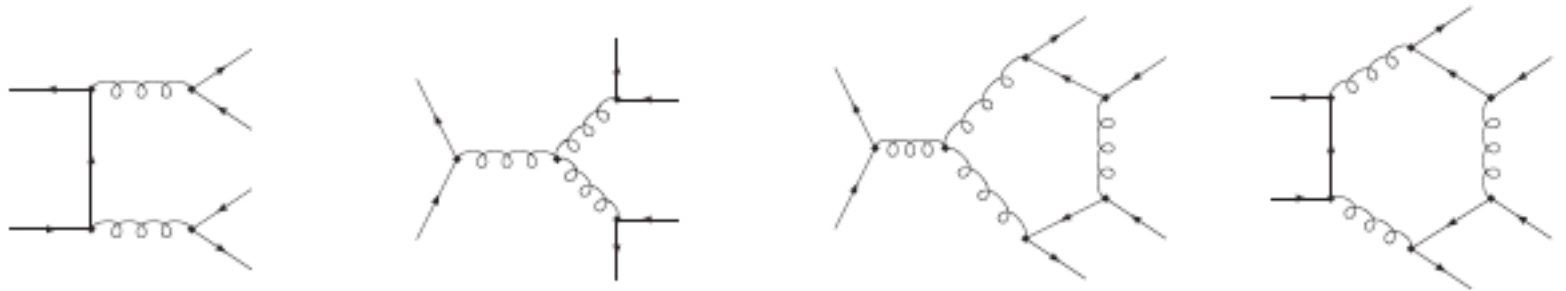
Simplistic rule

$$C_{i1} + C_{i2} - C_{f,\text{max}}$$

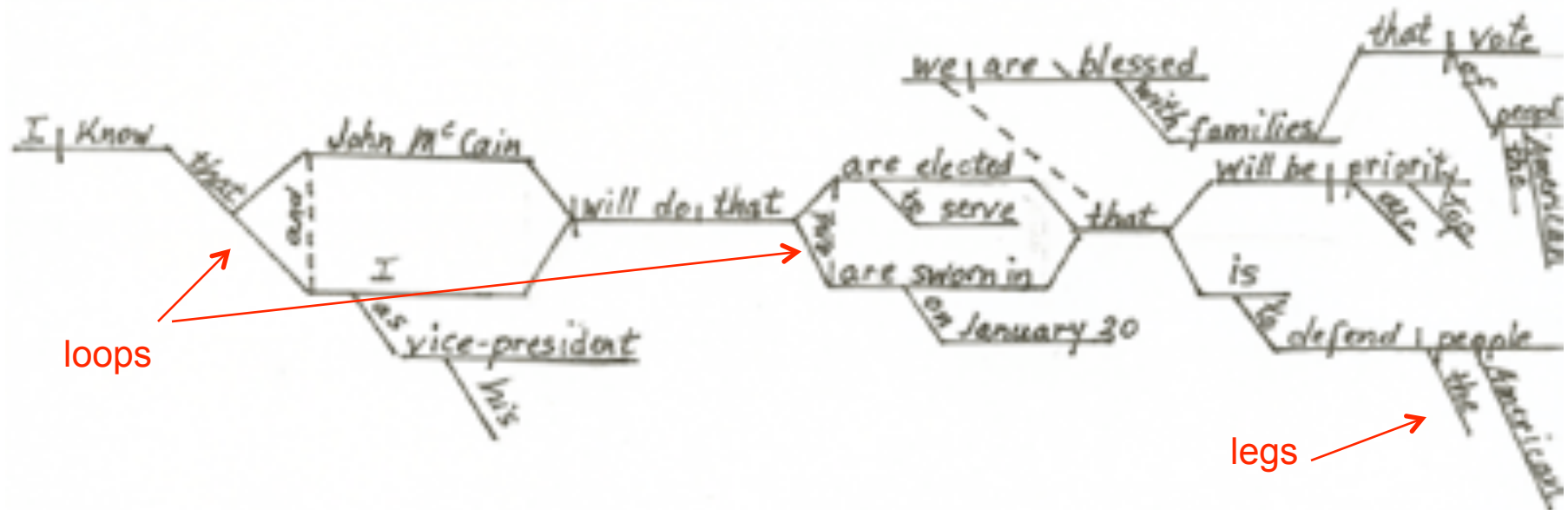
Casimir color factors for initial state

Difficult calculations

I know that the multi-loop and multi-leg calculations that you are doing are very difficult



but just compare them to the complexity of the sentences that Sarah Palin uses in her quest for the vice-presidency.



Don't forget

- NNLO: we need to know some processes (such as inclusive jet production) at NNLO
- Resummation effects: affect important physics signatures
 - ◆ mostly taken into account if NLO calculations can be linked with parton showering Monte Carlos

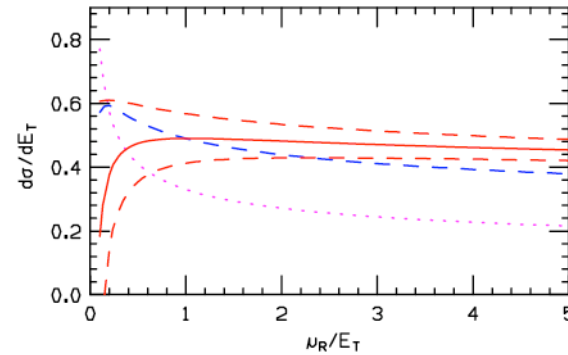


Figure 16. The single jet inclusive distribution at $E_T = 100$ GeV, appropriate for Run I of the Tevatron. Theoretical predictions are shown at LO (dotted magenta), NLO (dashed blue) and NNLO (red). Since the full NNLO calculation is not complete, three plausible possibilities are shown.

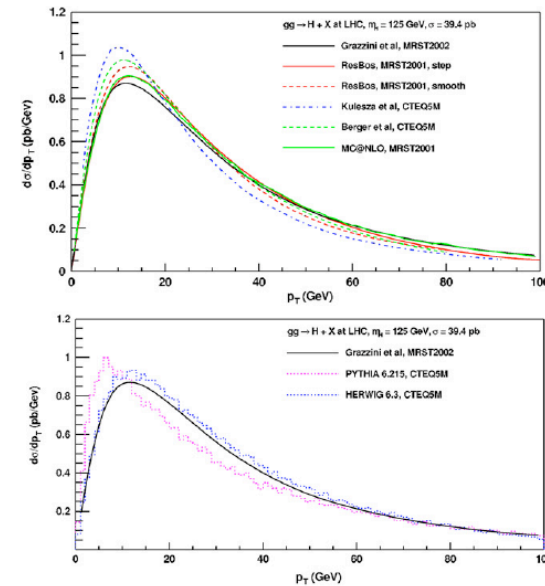


Figure 102. The predictions for the transverse momentum distribution for a 125 GeV mass Higgs boson at the LHC from a number of theoretical predictions. The predictions have all been normalized to the same cross section for shape comparisons. This figure can also be viewed in colour on the benchmark website.

...and

- BFKL logs: will we finally see them at the LHC?

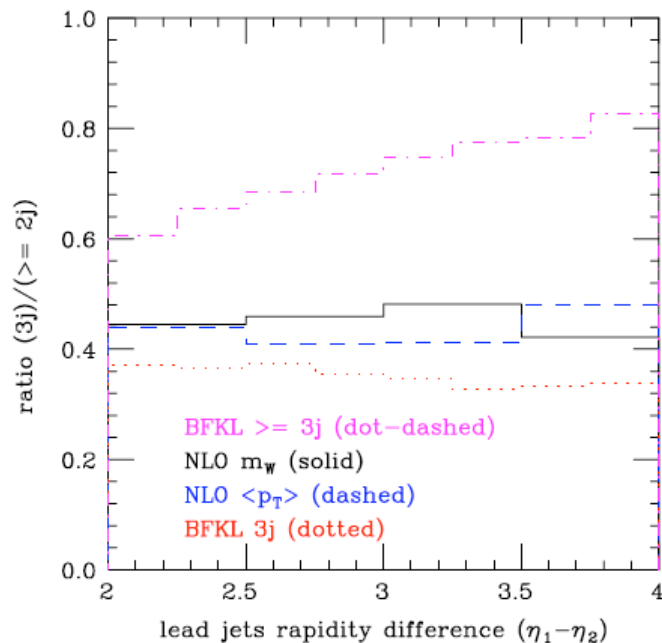


Figure 92. The rate for production of a third (or more) jet in $W + \geq 2$ jet events as a function of the rapidity separation of the two leading jets. A cut of 20 GeV has been placed on all jets. Predictions are shown from MCFM using two values for the renormalization and factorization scale, and using the BFKL formalism, requiring either that there be exactly 3 jets or 3 or more jets.

- EW logs: $\alpha_W \log^2(p_T^2/m_W^2)$ can be a big number at the LHC

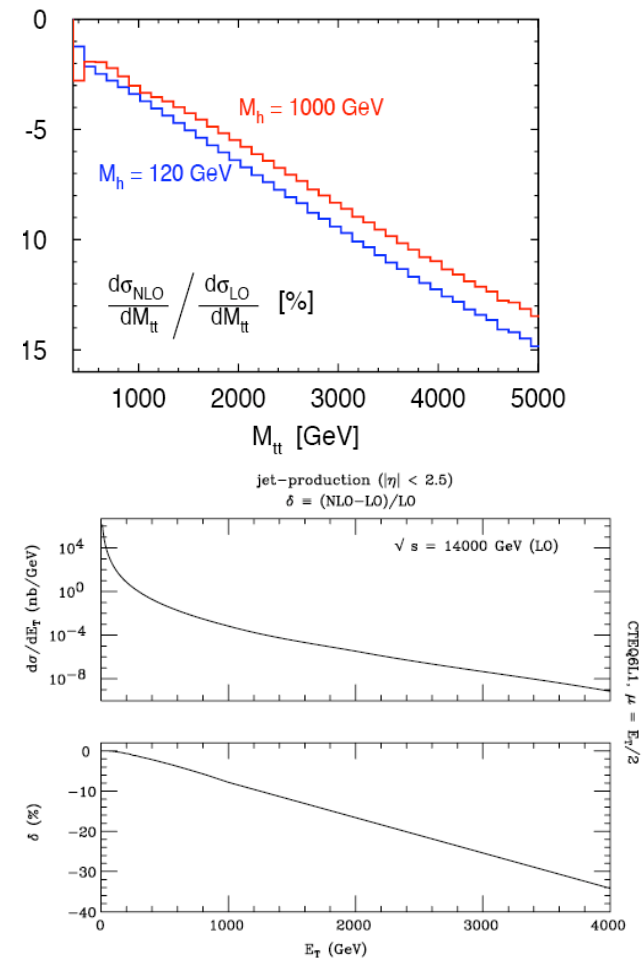


Figure 107. The effect of electroweak logarithms on jet cross sections at the LHC.

Back to LO: modified LO pdf's (LO*)

- What about pdf's for parton shower Monte Carlos?
 - ◆ standard has been to use LO pdf's, most commonly CTEQ5L/CTEQ6L, in Pythia, Herwig, Sherpa, ALPGEN/Madgraph+...
- ...but
 - ◆ LO pdf's can create LHC cross sections/acceptances that differ in both shape and normalization from NLO
 - ▲ due to influence of HERA data
 - ▲ and lack of $\ln(1/x)$ and $\ln(1-x)$ terms in leading order pdf's and evolution
 - ◆ ...and are often outside NLO error bands
 - ◆ experimenters use the NLO error pdf's in combination with the central LO pdf even with this mis-match
 - ▲ causes an error in pdf re-weighting
 - ◆ predictions for inclusive observables from LO matrix elements for many of the collider processes that we want to calculate are not so different from those from NLO matrix elements (aside from a reasonably constant K-factor)

Modified LO pdf's (LO*)

- ...but
 - ◆ we *like* the low x behavior of LO pdf's and rely upon them for our models of the underlying event at the Tevatron and its extrapolation to the LHC
 - ◆ as well as calculating low x cross sections at the LHC
- ...and people didn't listen to me when I said to use NLO pdf's in MC's
- thus, the need for modified LO pdf's

CTEQ talking points

- LO* pdf's should behave as LO as $x \rightarrow 0$; as close to NLO as possible as $x \rightarrow 1$
- LO* pdf's should be universal, i.e. results should be reasonable run on any platform with nominal physics scales
- It should be possible to produce error pdf's with
 - ◆ similar Sudakov form factors
 - ◆ similar UE
 - ◆ so pdf re-weighting makes sense
- LO* pdf's should describe underlying event at Tevatron with a tune similar to CTEQ6L (for convenience) and extrapolate to a *reasonable* UE at the LHC

CTEQ techniques

- Include in LO* fit (weighted) pseudo-data for characteristic LHC processes produced using CTEQ6.6 NLO pdf's with NLO matrix elements (using MCFM), along with full CTEQ6.6 dataset (2885 points)

- ◆ low mass bB
 - ▲ fix low x gluon for UE
- ◆ tT over full mass range
 - ▲ higher x gluon
- ◆ W^+, W^-, Z^0 rapidity distributions
 - ▲ quark distributions
- ◆ gg→H (120 GeV) rapidity distribution

Choices

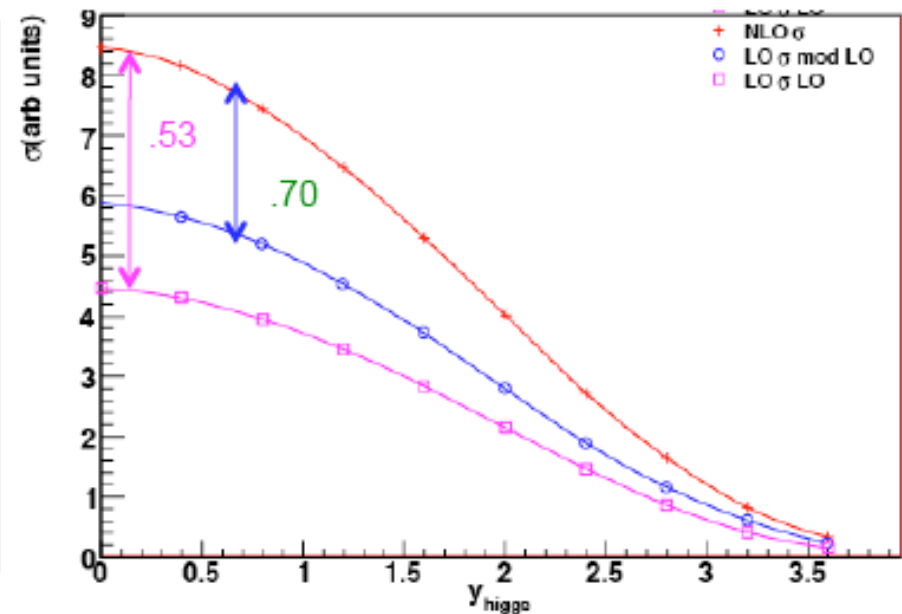
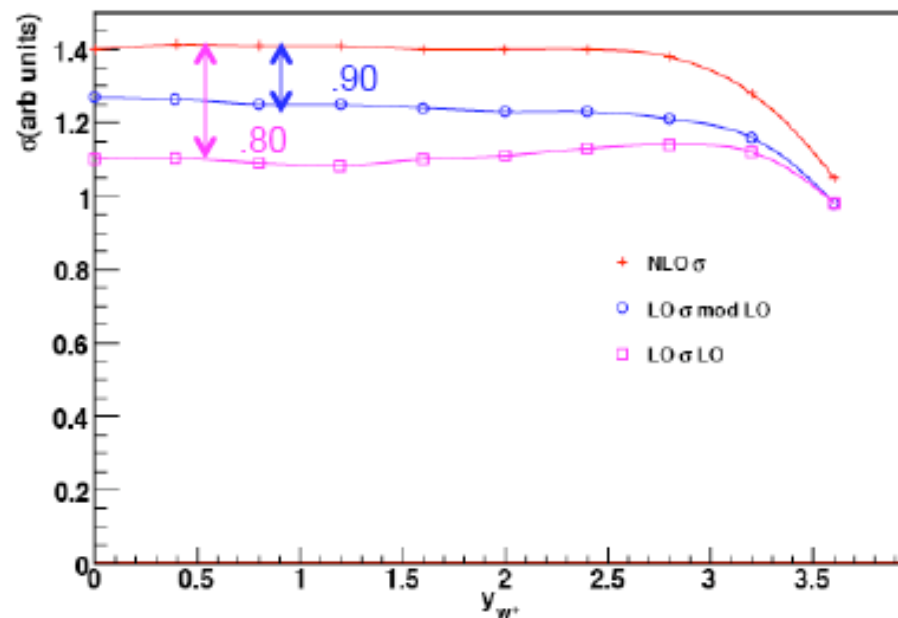
- Use of 2-loop or 1-loop α_s
 - ◆ MC preference for 2-loop?
- Fixed momentum sum rule, or not
 - ◆ re-arrange momentum within proton and/or add extra momentum
 - ◆ extra momentum appreciated by some of pseudo-data sets but not others and may lose some useful correlations
- Fix pseudo-data normalizations to K-factors expected from higher order corrections, or let float
- Scale variation within reasonable range for fine-tuning of agreement with pseudo-data
 - ◆ for example, let vector boson scale vary from 0.5 m_B to 2.0 m_B
- Will provide pdf's with several of these options for user

Some observations

- Pseudo-data has conflicts with global data set
 - ◆ that's the motivation of the modified pdf's
- Requiring better fit to pseudo-data increases chisquare of LO fit to global data set (although this is not the primary concern; the fit to the pseudo-data is)
 - ◆ χ^2 improves with α_s free in fit
 - ◆ χ^2 improves with momentum sum rule free
 - ▲ prefers more momentum, smaller α_s
 - ▲ normalization of pseudo-data (needed K-factor) gets closer to 1
 - ▲ still some conflicts with DIS data that don't prefer more momentum
 - ◆ χ^2 typically improves if K-factors can vary from values given in previous slide

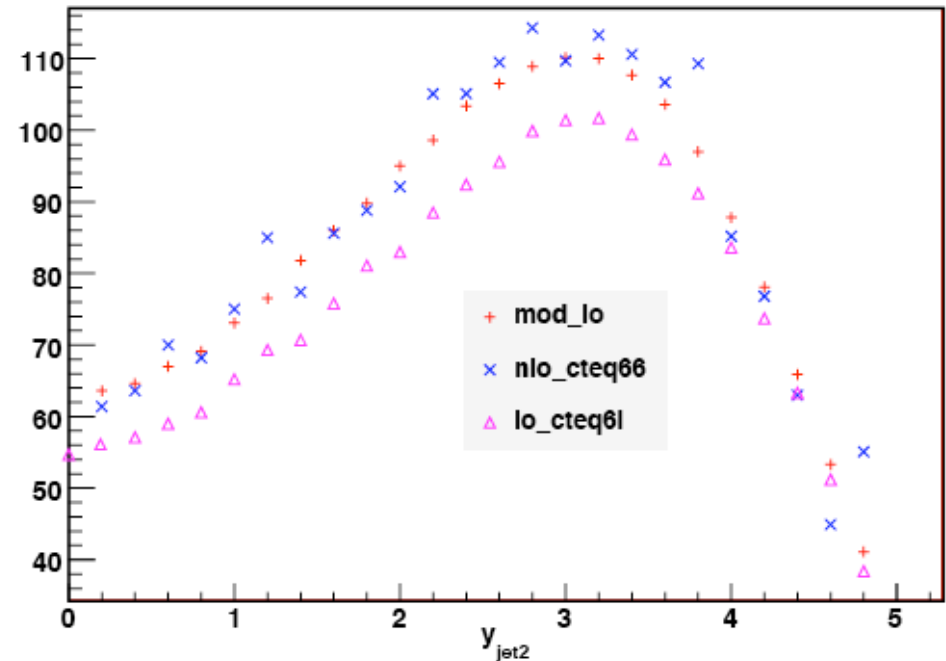
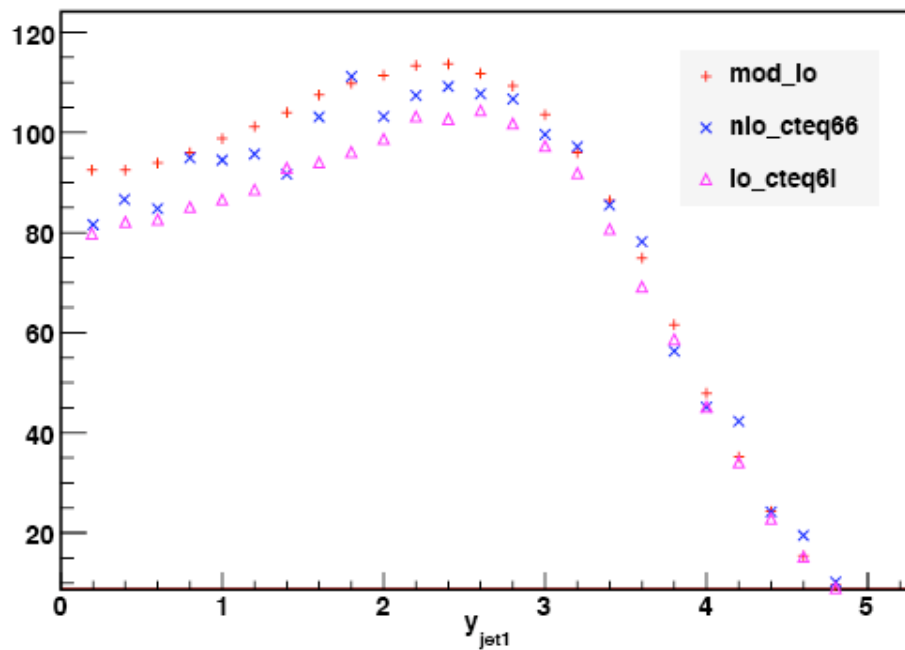
Some results

- Rapidity distributions for W^+ and Higgs from pure NLO, LO with LO pdf, LO with CTEQ modified LO pdf
- Momentum sum=1.06 for CTEQ modified LO pdf
 - ◆ why so much less than mod MSTW?
- $\alpha_s(m_Z)=0.124$ for CTEQ modified LO pdf
- tT normalization is 0.76



VBF Higgs

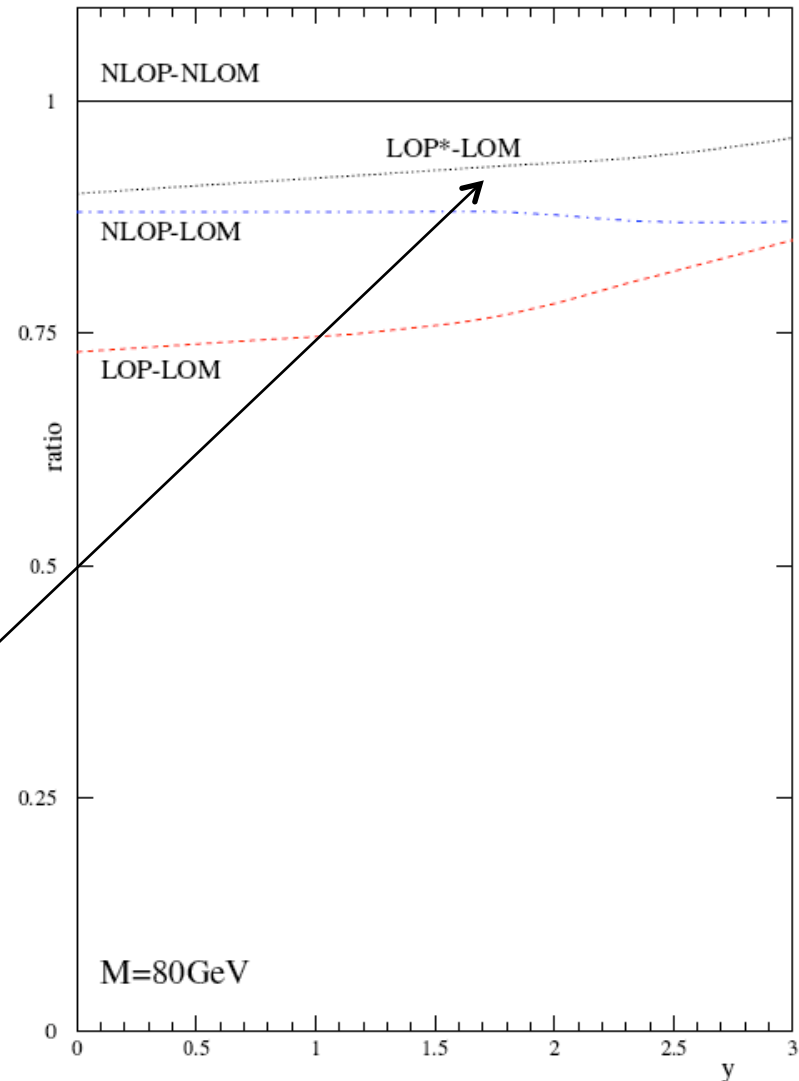
Below are the rapidity distributions for the two tagging jets in VBF production of a 120 GeV Higgs at the LHC. The modified LO pdf gives a better description of the shape of the jet rapidity distributions, especially for the 2nd jet. The NLO cross section using CTEQ6.6 is 4.1 pb. The LO cross section using CTEQ6L is 3.8 pb and using the modified LO pdf is 4.2 pb. These pseudo-data were not in the fit but are sensitive to the high x quark distributions.



MRSTLO*

- The MRST group has a modified LO pdf that tries to incorporate many of the points mentioned on the previous slides
- They relax the momentum sum rule (114%) and achieve a better agreement (than MRST LO pdf's) with some important LHC benchmark cross sections

Drell-Yan Cross-section at LHC for 80 GeV with Different Orders



Now some technical stuff

- Consider a cross section $X(a)$
- i^{th} component of gradient of X is

$$\frac{\partial X}{\partial a_i} \equiv \partial_i X = \frac{1}{2}(X_i^{(+)} - X_i^{(-)})$$

- Now take 2 cross sections X and Y
 - or one or both can be pdf's
- Consider the projection of gradients of X and Y onto a circle of radius 1 in the plane of the gradients in the parton parameter space
- The circle maps onto an ellipse in the XY plane
- The angle ϕ between the gradients of X and Y is given by

$$\cos \varphi = \frac{\vec{\nabla} X \cdot \vec{\nabla} Y}{\Delta X \Delta Y} = \frac{1}{4 \Delta X \Delta Y} \sum_{i=1}^N \left(X_i^{(+)} - X_i^{(-)} \right) \left(Y_i^{(+)} - Y_i^{(-)} \right)$$

- The ellipse itself is given by

$$\left(\frac{\delta X}{\Delta X} \right)^2 + \left(\frac{\delta Y}{\Delta Y} \right)^2 - 2 \left(\frac{\delta X}{\Delta X} \right) \left(\frac{\delta Y}{\Delta Y} \right) \cos \varphi = \sin^2 \varphi$$

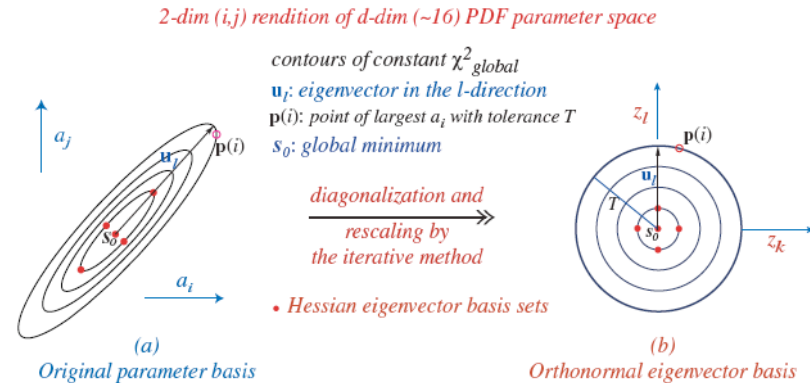


Figure 28. A schematic representation of the transformation from the pdf parameter basis to the orthonormal eigenvector basis.

- If two cross sections are very correlated, then $\cos \phi \sim 1$
- ...uncorrelated, then $\cos \phi \sim 0$
- ...anti-correlated, then $\cos \phi \sim -1$

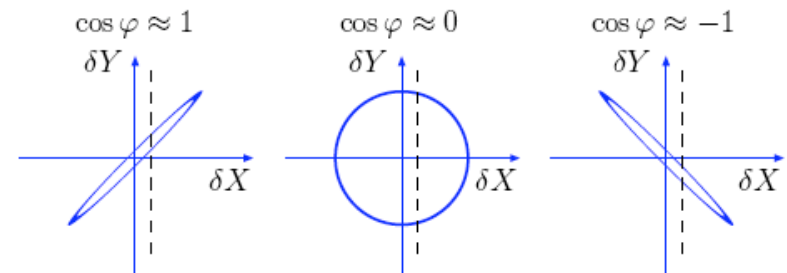


Figure 1: Dependence on the correlation ellipse formed in the $\Delta X - \Delta Y$ plane on the value of the correlation cosine $\cos \varphi$.

Correlations with Z, tT

Define a correlation cosine between two quantities

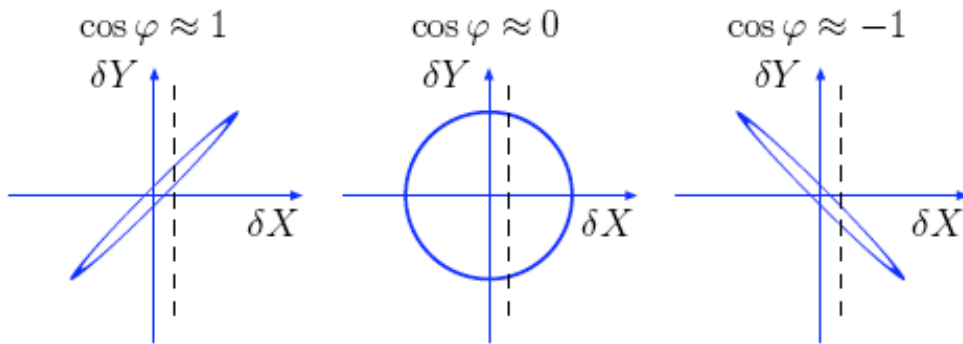
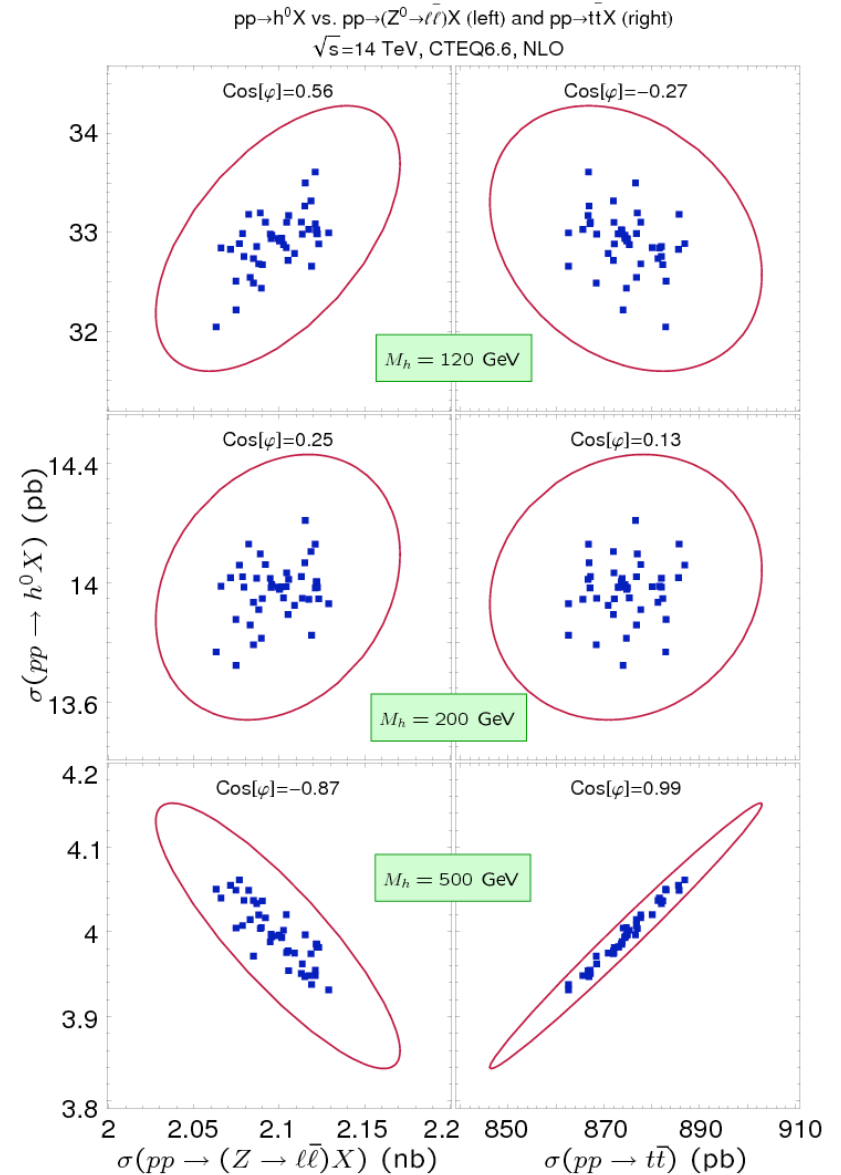


Figure 1: Dependence on the correlation ellipse formed in the $\Delta X - \Delta Y$ plane on the value of the correlation cosine $\cos \varphi$.

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Correlations with Z, tT

Define a correlation cosine between two quantities

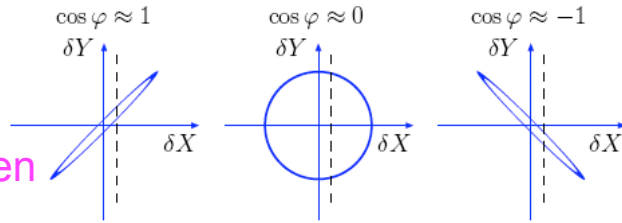
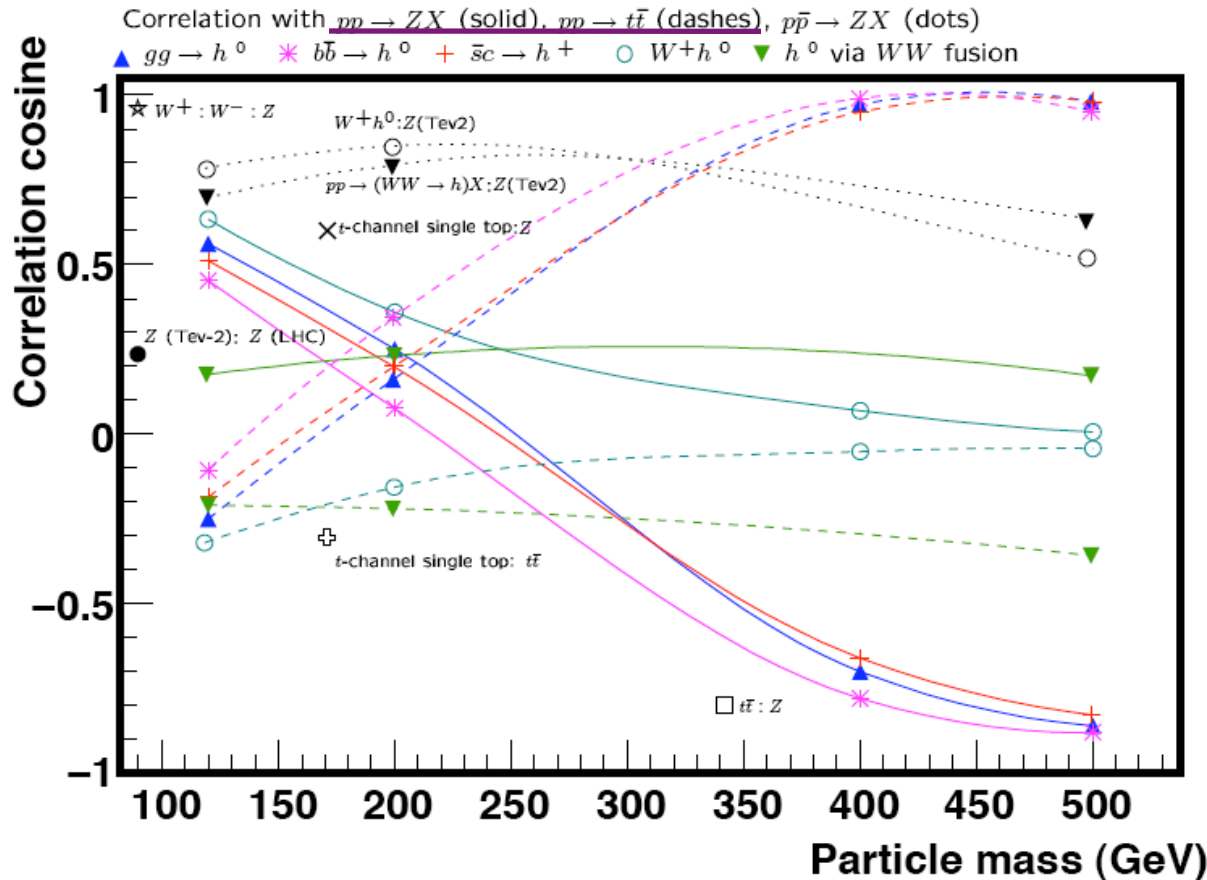


Figure 1: Dependence on the correlation ellipse formed in the $\Delta X - \Delta Y$ plane on the value of the correlation cosine $\cos \phi$.

- If two cross sections are very correlated, then $\cos \phi \sim 1$
- ...uncorrelated, then $\cos \phi \sim 0$
- ...anti-correlated, then $\cos \phi \sim -1$



- Note that correlation curves to Z and to tT are mirror images of each other

- By knowing the pdf correlations, can reduce the uncertainty for a given cross section in ratio to a benchmark cross section **iff** $\cos \phi > 0$; e.g. $\Delta(\sigma_W + \sigma_Z) \sim 1\%$

- If $\cos \phi < 0$, pdf uncertainty for one cross section normalized to a benchmark cross section is larger

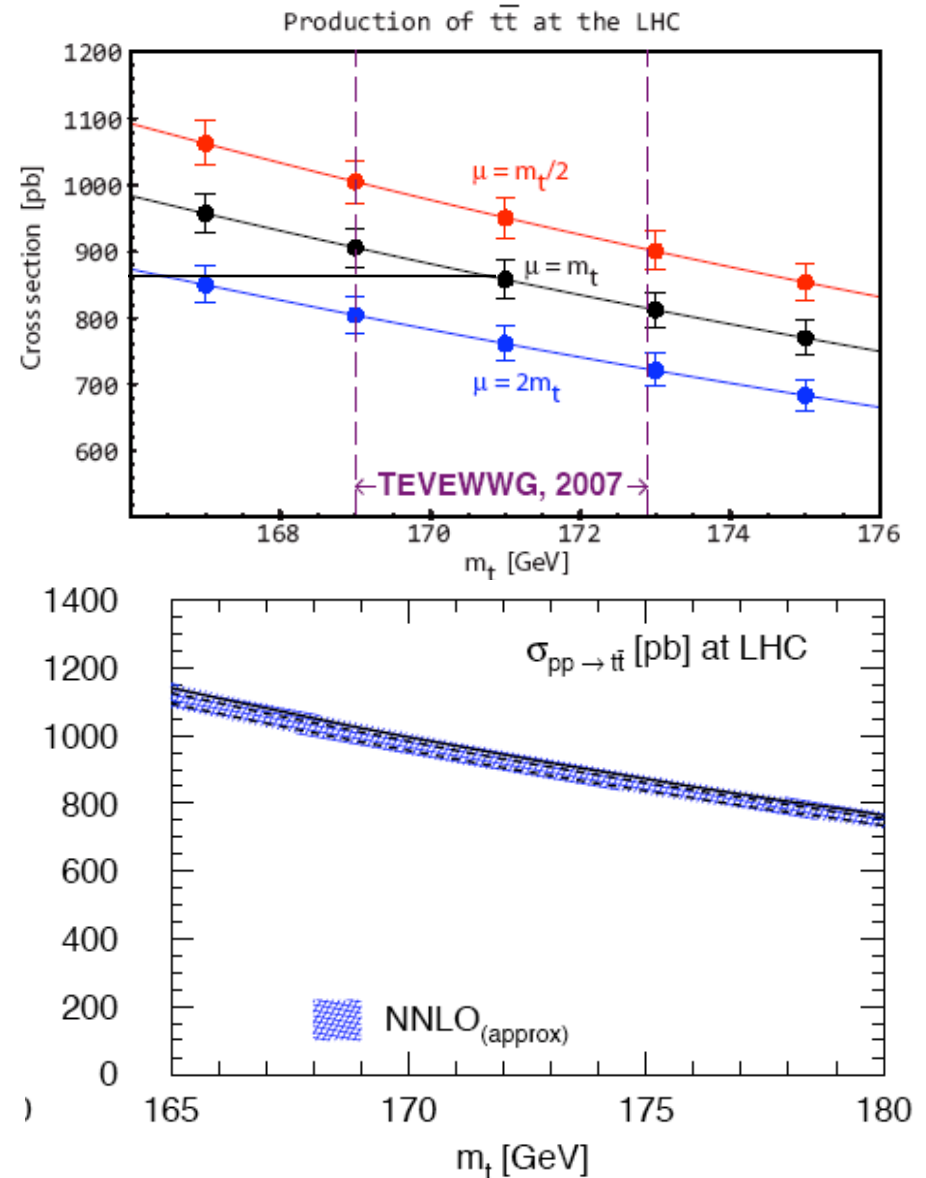
- So, for $gg \rightarrow H(500 \text{ GeV})$; pdf uncertainty is 4%; $\Delta(\sigma_H / \sigma_Z) \sim 8\%$

W/Z summary so far

- We will use W and Z cross sections as luminosity normalizations in early running and perhaps always
 - ◆ because integrated luminosity is not going to be known much better than 15-20% at first and maybe never better than 5-10%
- The pdf uncertainty for the ratio of a cross section that proceeds with a qQ initial state to the W/Z cross section is significantly reduced
- The pdf uncertainty for the ratio of a cross section that proceeds with a gg initial state to the W/Z cross section is significantly increased
- Would it be reasonable to use tT production as an additional normalization tool?
 - ◆ yeah, yeah I know it's difficult

Theory uncertainties for tT at LHC

- Note that at NLO with CTEQ6.6 pdf's the central prediction for the tT cross section for $\mu=m_t$ is ~ 850 pb (not 800 pb, which it would be if the top mass were 175 GeV); ~ 880 pb if use effect of threshold resummation
- The scale dependence is around $\pm 11\%$ and mass dependence is around $\pm 6\%$
- Tevatron plans to measure top mass to < 1 GeV
 - mass dependence goes to $\sim \pm 3\%$
- NNLO tT cross section will be finished in near future
 - scale dependence will drop
 - threshold resummation reduces scale dependence to $\sim 3\%$ (Moch and Uwer)
- tT still in worse shape than W/Z, but not by too much
 - and pdf uncertainty is (a bit) smaller



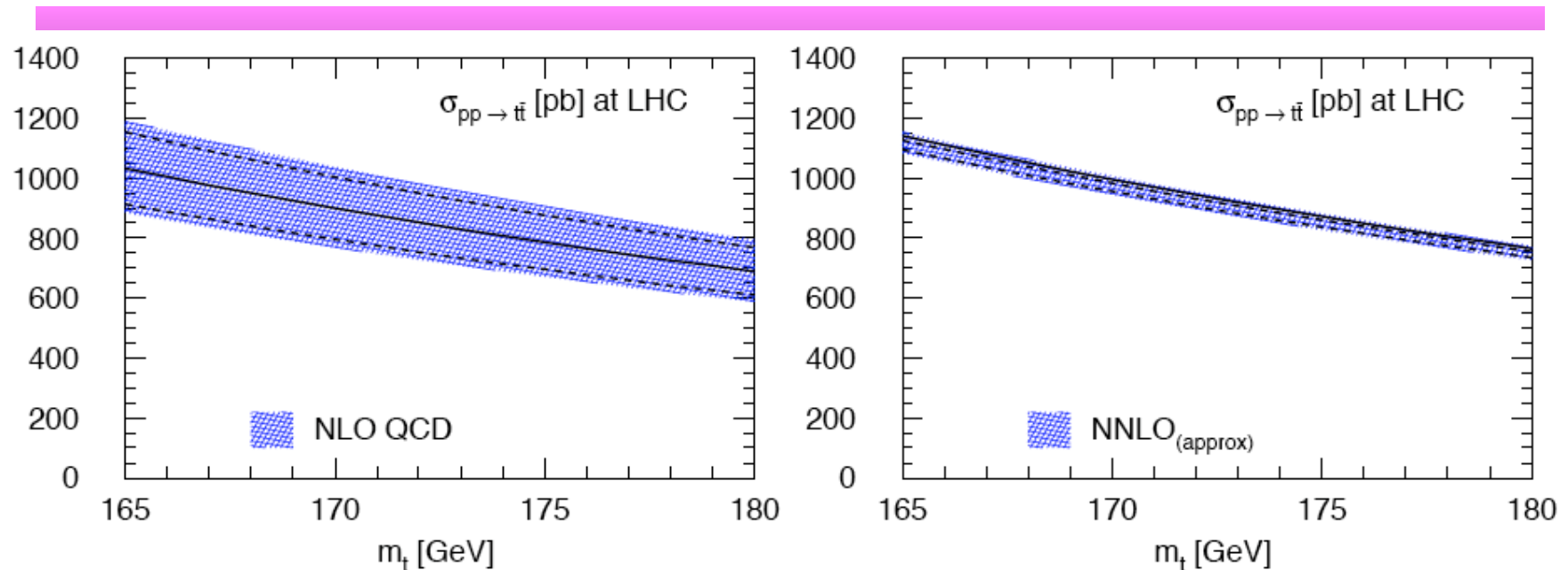
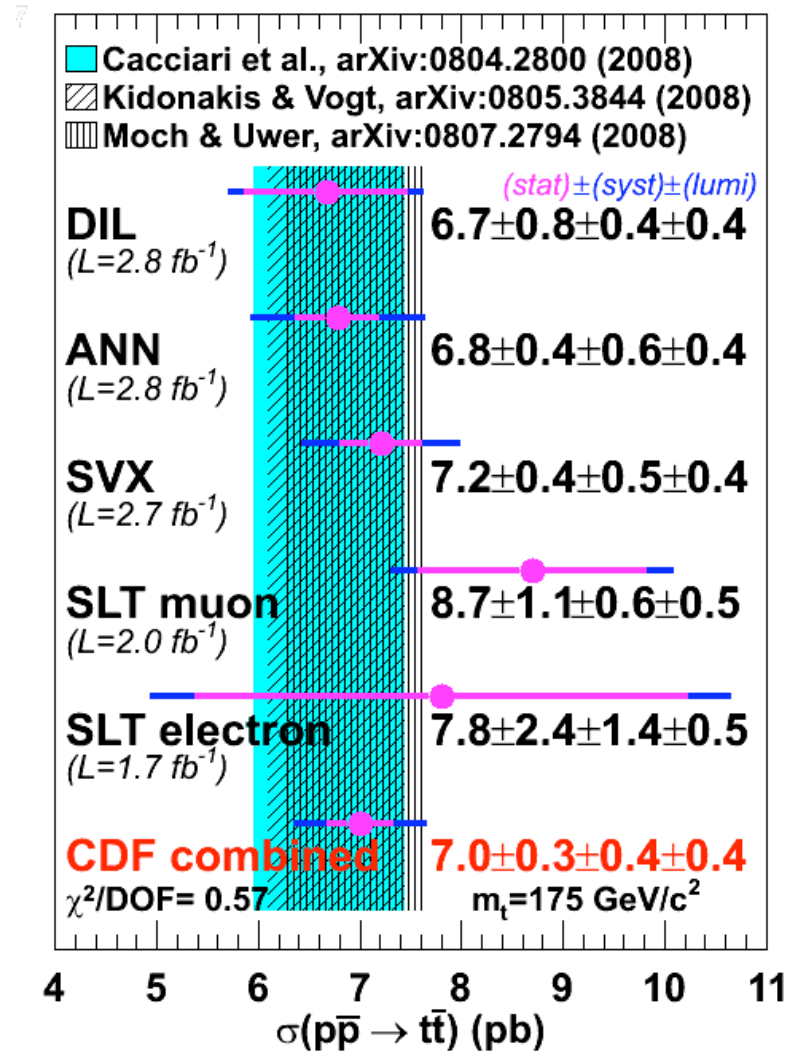


Figure 9: The NNLO (approx) QCD prediction for the $t\bar{t}$ total cross section at LHC as functions of m_t for $\sqrt{s_{\text{had}}} = 14$ TeV (right). The solid line is the central value for $\mu = m_t$, the dashed lower and upper lines correspond to $\mu = 2m_t$ and $\mu = m_t/2$, respectively. The band denotes the total uncertainty that is the uncertainty due to scale variations and the PDF uncertainty of the MRST-2006 NNLO set [24]. For comparison the left plot shows the corresponding prediction at NLO accuracy using the PDF set CTEQ6.5 [23].

Another question for the audience: if you use different values for the renormalization and factorization scales, are you just introducing artificial logs that will be compensated in the (next) higher order calculation anyway?

What about experimental uncertainties?

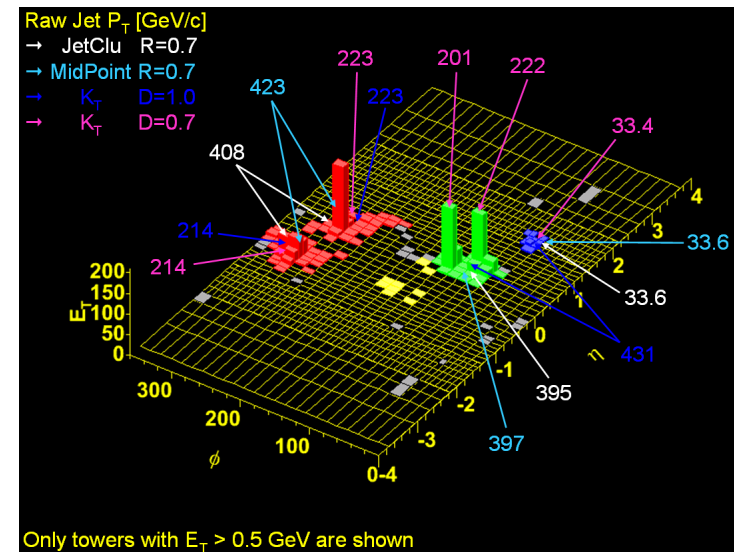
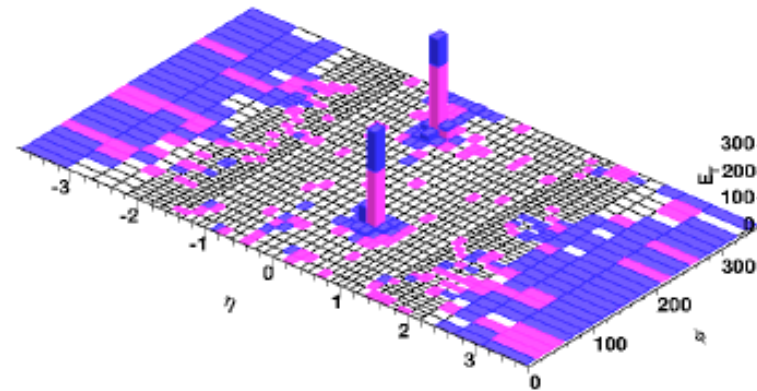
- 10-15% in first year
 - ◆ unfortunately, which is where we would most like to have a precise value
- Ultimately, ~5%?
 - ◆ dominated by b-tagging uncertainty?
 - ◆ systematic errors in common with other complex final states, which may cancel in a ratio?
- Tevatron now does 8% (non-lum)



Last but not least: Jet algorithms

- For some events, the jet structure is very clear and there's little ambiguity about the assignment of towers/particles to the jet
- But for other events, there is ambiguity and the jet algorithm must make decisions that impact precision measurements
- There is the tendency to treat jet algorithms as one would electron or photon algorithms
- There's a much more dynamic structure in jet formation that is affected by the decisions made by the jet algorithms and which we can tap in
- ATLAS, with its fine segmentation and the ability to make topoclusters, has perhaps the most powerful jet capabilities in any hadron collider experiment to date...if we take full advantage of what the experiment offers (and use SpartyJet)
- Analyses should be performed with multiple jet algorithms, if possible

CDF Run II events



→ SIScone, k_T , anti- k_T (my suggestions)

Some recommendations from jet paper

- 4-vector kinematics (p_T, y and not E_T, η) should be used to specify jets
- Where possible, analyses should be performed with multiple jet algorithms
- For cone algorithms, split/merge of 0.75 preferred to 0.50

CTEQ4LHC/FROOT

- Collate/create cross section predictions for LHC
 - ◆ processes such as W/Z/ Higgs(both SM and BSM)/ diboson/tT/single top/photons/ jets...
 - ◆ at LO, NLO, NNLO (where available)
 - ▲ new: W/Z production to NNLO QCD and NLO EW
 - ◆ pdf uncertainty, scale uncertainty, correlations
 - ◆ impacts of resummation (q_T and threshold)
- As prelude towards comparison with actual data
- Using programs such as:
 - ◆ MCFM
 - ◆ ResBos
 - ◆ Pythia/Herwig/Sherpa
 - ◆ ... private codes with CTEQ
- First on webpage and later as a report

Primary goal: have all theorists (**including you**) write out parton level output into ROOT ntuples

Secondary goal: make libraries of prediction ntuples available

- FROOT: a simple interface for writing Monte-Carlo events into a ROOT ntuple file
- Written by Pavel Nadolsky (nadolsky@physics.smu.edu)
- CONTENTS
- =====
- froot.c -- the C file with FROOT functions
- taste_froot.f -- a sample Fortran program writing 3 events into a ROOT ntuple
- taste_froot0.c -- an alternative top-level C wrapper (see the compilation notes below)
- Makefile

PDF Uncertainties and FROOT

Z production in ResBos

The screenshot shows a Mac desktop with a ROOT Object Browser window and a file list window. The ROOT Object Browser window displays the contents of the directory `*/ROOT Files/resbos_lhc_z0.root/h10`. The file list window shows a list of files with columns for Name, Date Modified, and Size.

new way, all pdf weights stored in ntuple, events generated once

old way independent ntuple for each pdf

The file list window shows the following files:

Name	Date Modified	Size
res221_z0_lhc_aaana00.root	Aug 20, 2006, 2:54 PM	52.9 MB
res221_z0_lhc_aaana01.root	Aug 20, 2006, 2:55 PM	52.9 MB
res221_z0_lhc_aaana02.root	Aug 20, 2006, 2:55 PM	52.9 MB
res221_z0_lhc_aaana03.root	Aug 20, 2006, 2:55 PM	52.9 MB
res221_z0_lhc_aaana04.root	Aug 20, 2006, 2:55 PM	52.9 MB
res221_z0_lhc_aaana05.root	Aug 20, 2006, 2:55 PM	52.9 MB
res221_z0_lhc_aaana06.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana07.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana08.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana09.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana10.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana11.root	Aug 20, 2006, 2:56 PM	52.9 MB
res221_z0_lhc_aaana12.root	Aug 20, 2006, 2:57 PM	52.9 MB
res221_z0_lhc_aaana13.root	Aug 20, 2006, 2:57 PM	52.9 MB
res221_z0_lhc_aaana14.root	Aug 20, 2006, 2:57 PM	52.9 MB
res221_z0_lhc_aaana15.root	Aug 20, 2006, 2:57 PM	52.9 MB
res221_z0_lhc_aaana16.root	Aug 20, 2006, 2:57 PM	52.9 MB
res221_z0_lhc_aaana17.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana18.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana19.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana20.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana21.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana22.root	Aug 20, 2006, 2:58 PM	52.9 MB
res221_z0_lhc_aaana23.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana24.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana25.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana26.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana27.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana28.root	Aug 20, 2006, 2:59 PM	52.9 MB
res221_z0_lhc_aaana29.root	Aug 20, 2006, 3:00 PM	52.9 MB
res221_z0_lhc_aaana30.root	Aug 20, 2006, 3:00 PM	52.9 MB
res221_z0_lhc_aaana31.root	Aug 20, 2006, 3:00 PM	52.9 MB
res221_z0_lhc_aaana32.root	Aug 20, 2006, 3:00 PM	52.9 MB
res221_z0_lhc_aaana33.root	Aug 20, 2006, 3:00 PM	52.9 MB
res221_z0_lhc_aaana34.root	Aug 20, 2006, 3:01 PM	52.9 MB
res221_z0_lhc_aaana35.root	Aug 20, 2006, 3:01 PM	52.9 MB

The desktop background shows a green landscape. The dock at the bottom contains various application icons. The status bar at the bottom right indicates 69 items and 4.36 GB available.

MCFM with pdf errors (FROOT included in version 5.3)

- Error pdf parton luminosities stored along with other event information; tremendous time-saving for MCFM
- Example output below from tT at LHC with CTEQ6.1(virtual diagrams only)

```
PDF error set 0 ---> 922503.705 fb
PDF error set 1 ---> 924901.729 fb
PDF error set 2 ---> 920106.561 fb
PDF error set 3 ---> 926873.142 fb
PDF error set 4 ---> 918314.821 fb
PDF error set 5 ---> 924319.039 fb
PDF error set 6 ---> 920737.988 fb
PDF error set 7 ---> 930912.022 fb
PDF error set 8 ---> 914120.978 fb
PDF error set 9 ---> 944892.019 fb
PDF error set 10 ---> 899134.509 fb
PDF error set 11 ---> 910661.311 fb
PDF error set 12 ---> 933849.973 fb
PDF error set 13 ---> 918037.641 fb
PDF error set 14 ---> 926658.411 fb
PDF error set 15 ---> 929544.061 fb
PDF error set 16 ---> 916165.078 fb
PDF error set 17 ---> 926807.189 fb
PDF error set 18 ---> 918520.852 fb
PDF error set 19 ---> 914185.317 fb
PDF error set 20 ---> 928791.454 fb
PDF error set 21 ---> 916124.098 fb
PDF error set 22 ---> 919646.351 fb
PDF error set 23 ---> 922102.562 fb
```

```
PDF error set 24 ---> 920512.494 fb
PDF error set 25 ---> 923791.211 fb
PDF error set 26 ---> 919567.536 fb
PDF error set 27 ---> 924333.235 fb
PDF error set 28 ---> 922540.280 fb
PDF error set 29 ---> 917348.784 fb
PDF error set 30 ---> 933489.451 fb
PDF error set 31 ---> 921711.144 fb
PDF error set 32 ---> 920739.212 fb
PDF error set 33 ---> 919592.767 fb
PDF error set 34 ---> 923451.843 fb
PDF error set 35 ---> 923859.904 fb
PDF error set 36 ---> 923632.556 fb
PDF error set 37 ---> 923740.945 fb
PDF error set 38 ---> 921204.429 fb
PDF error set 39 ---> 922465.341 fb
PDF error set 40 ---> 922560.436 fb
```

```
* ----- SUMMARY -----
*      Minimum value      899134.509 fb
*      Central value      922503.705 fb
*      Maximum value      944892.019 fb
*      Err estimate +/- 31131.272 fb
*      +ve direction      31383.680 fb
*      -ve direction      32098.504 fb
```

```
*****
```

real diagrams contribute -70000 fb, so
central NLO is ~850 pb; threshold resum->880 pb

Summary



- Physics will come flying hot and heavy when LHC turns on in ~~2008~~ 2009
- Important to establish both the SM benchmarks and the tools we will need to properly understand this flood of data
- Physics will continue to fly out of the Tevatron through 2009 and 2010
 - ◆ with detectors and analysis software already well-understood

• Physics isn't flying out of CTEQ at the same rate as at the Tevatron but we're preparing papers on

- update to NLO pdf's
 - recent Tevatron data
- modified LO pdf's
 - perhaps 2 flavors
- combined (x and q_t) pdf fits
- NNLO

• ...and it's not too early to be thinking about Les Houches 2009



June 8-26, 2009

Bonus feature



Correlations: W/Z and pdf's

- At the Tevatron, W and Z cross sections most correlated with u,U,d,D pdf's

- At the LHC, W and Z cross sections most correlated with charm, bottom and gluon distributions

- A large correlation with the gluon for x values ~ 0.005 is accompanied by a large anti-correlation with the gluon at larger x

- This implies a strong anti-correlation of W and Z with heavy states produced by gg

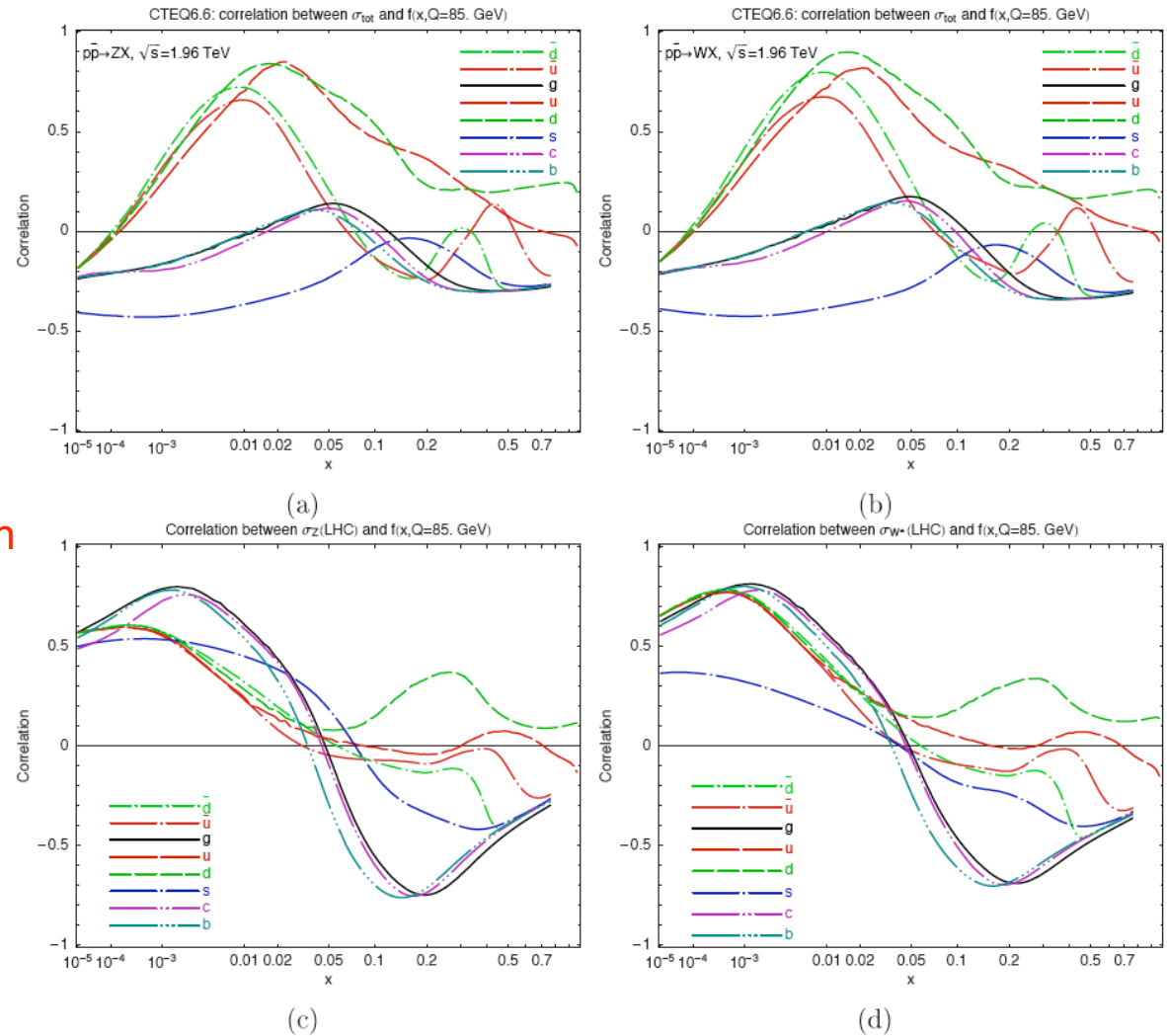


Figure 10: (a,b) Correlation between the total cross sections for Z^0 and W^\pm production at the Tevatron and PDF's of various flavors, plotted as a function of x for $Q = 85 \text{ GeV}$; (c,d) the same for the LHC

Correlations: Z to W ratio

- The ratio of the Z to W cross section is most strongly correlated with the strange quark distribution

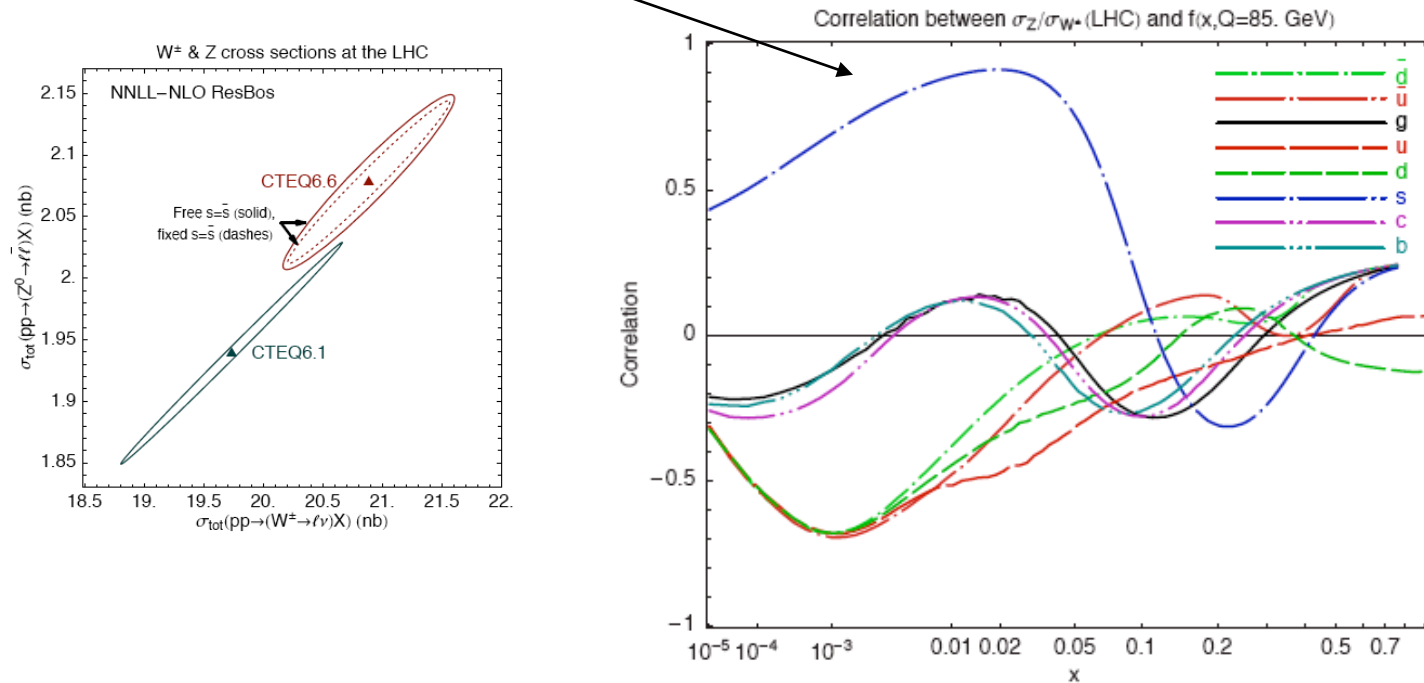


Figure 11: Correlation between the ratio σ_Z/σ_W of LHC total cross sections for Z^0 and W^{\pm} production at PDF's of various flavors, plotted as a function of x for $Q = 85 \text{ GeV}$.

SpartyJet



Sparty

J. Huston, K. Geerlings
Michigan State University

P-A. Delsart, LAPP

SpartyJet

What is SpartyJet?

- “a framework intended to allow for the easy use of multiple jet algorithms in collider analyses”
 - Fast** to run, no need for heavy framework
 - Easy** to use, basic operation is very simple
 - Flexible**
 - ROOT-script or standalone execution
 - “on-the-fly” execution for event-by-event results
 - many different input types
 - different algorithms
 - output format

JetBuilder

- basically a frontend to handle most of the details of running SpartyJet
- not necessary, but makes running SpartyJet **much** simpler
- Allows options that are not otherwise accessible
 - text output
 - add minimum bias events

```
gSystem->Load("libTree.so");
gSystem->Load("libAlgoCore.so");
gSystem->Load("libCDFJet");
std::ifstream input("data/1_Clusters.dat");
JetBuilder builder;
builder.configure_input((InputMaker*)&textinput);
builder.add_default_alg(new cdf::JetClusFinder("myJetClu"));
builder.set_default_cut(0.1*textinput.getGeV());
builder.configure_output("SpartyJet_Tree", "data/output/simple.root");
builder.process_events(10);
```

```
True if /home/deisart/spartyjet/vwithStc/06/example/data/small.root/
TTree *tree = (TTree*) f->Get("CollectionTree");
atlas::CBNTInput input;
input.init(tree);
JetAlgorithm *alg = new JetAlgorithm("MidPointJets");
JetPSelectorTool *selec = new JetPSelectorTool(1*GeV);
MidPoint *midpoint = new MidPoint("TOTOT");
alg->addTool((JetTool*)midpoint);
alg->addTool((JetTool*)selec);
alg->init();
NtupleMaker ntp;
ntp.addJetVar("MidPointJets");
ntp.init("jetTree", "out.root");
Jet::jet_list_t jets;
Jet::jet_list_t outjets;
input->fillInput(2, jets);
alg->execute(injets, outjets);
ntp.set_data("MidPointJets", outjets);
ntp.fillJets();
clear_jetlist(injets);
clear_jetlist(outjets);
input->fillInput(5, jets);
alg->execute(injets, outjets);
ntp.set_data("MidPointJets", outjets);
ntp.fillJets();
ntp.finalize();
```

without JetBuilder

Available Algorithms

- CDF
 - JetClu
 - MidPoint (with optional second pass)
- D0
 - D0RunIICone
- (from Lars Sonnenschein)
- ATLAS
 - Cone
 - FastKt
- FastJet (from Gavin Salam and Matteo Cacciari)
 - FastKt
 - Seedless Infrared Safe Cone (SISCone)
- Pythia 8
 - CellJet

all algorithms are fully parameterizable

“on-the-fly” method

- no input data file, no output data file
- from other C++ programs, call a variant of `jets = SpartyJet::getjets(JetTool*, data)`
- Currently supported data types:

```
Jet::jet_list_t& SpartyJet::getjets( JetTool* tool
Jet::jet_list_t& inputJets);

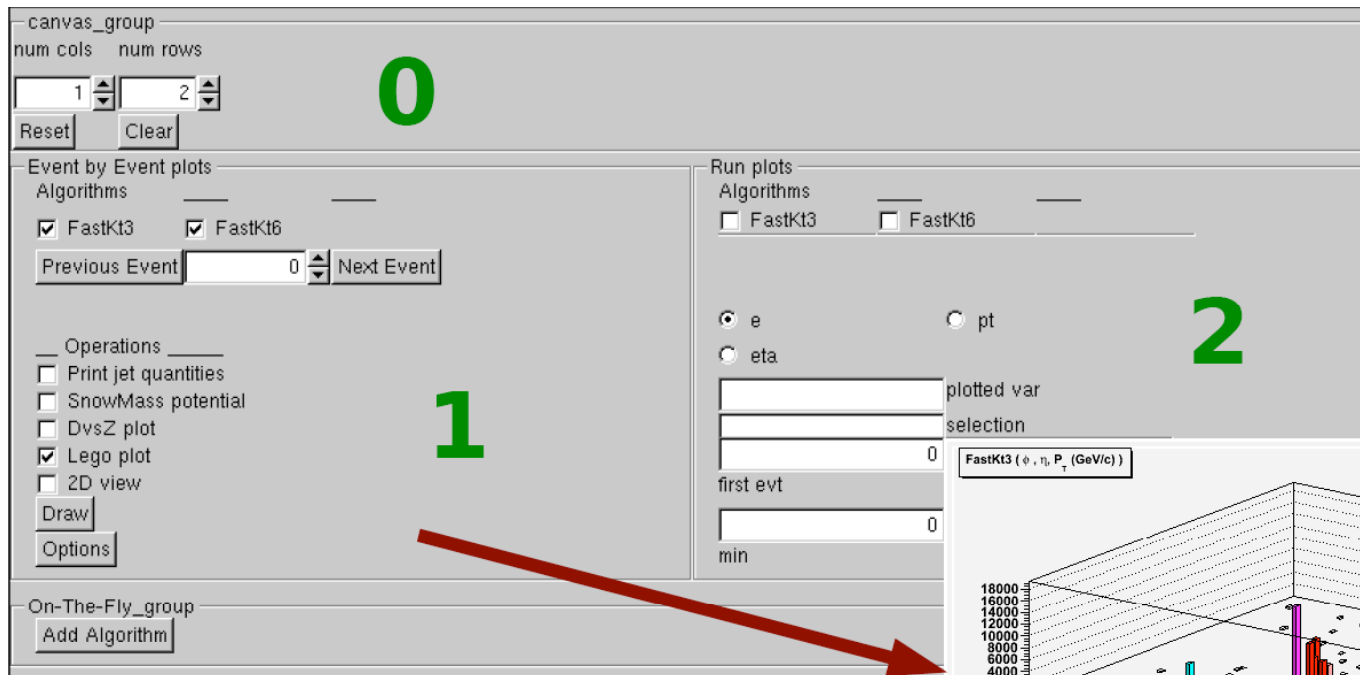
std::vector<TLorentzVector>& SpartyJet::getjets( JetTool* tool
std::vector<TLorentzVector>& input);

std::vector<TLorentzVector>& SpartyJet::getjets( JetTool* tool
std::vector<TLorentzVector>& input,
std::vector<std::vector<int>>& constituents);

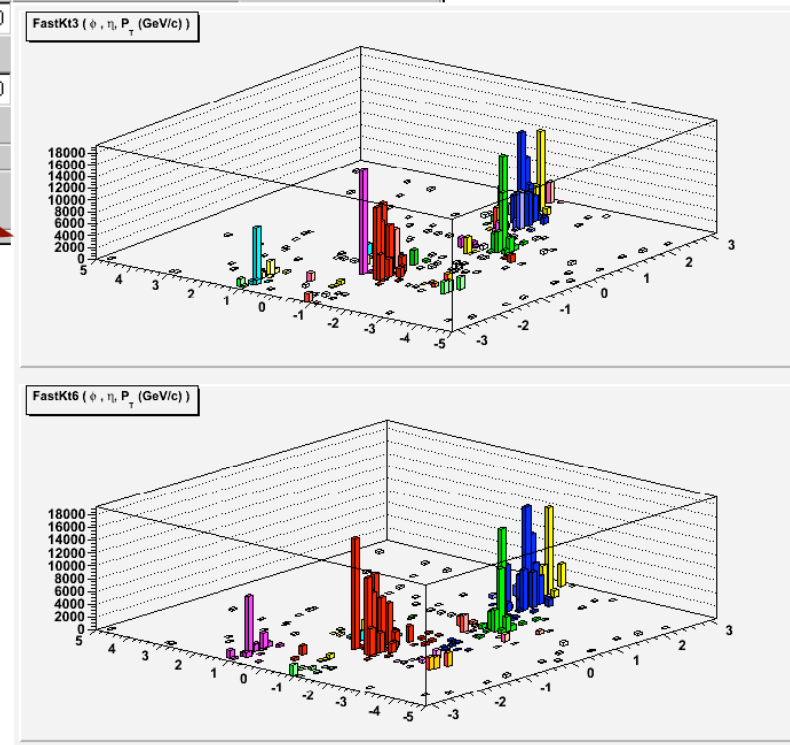
std::vector<SpartyJet::simplejet> SpartyJet::getjets( JetTool* tool
std::vector<simplejet>& input);
```

reconstruct individual jets with new parameters in context of analysis

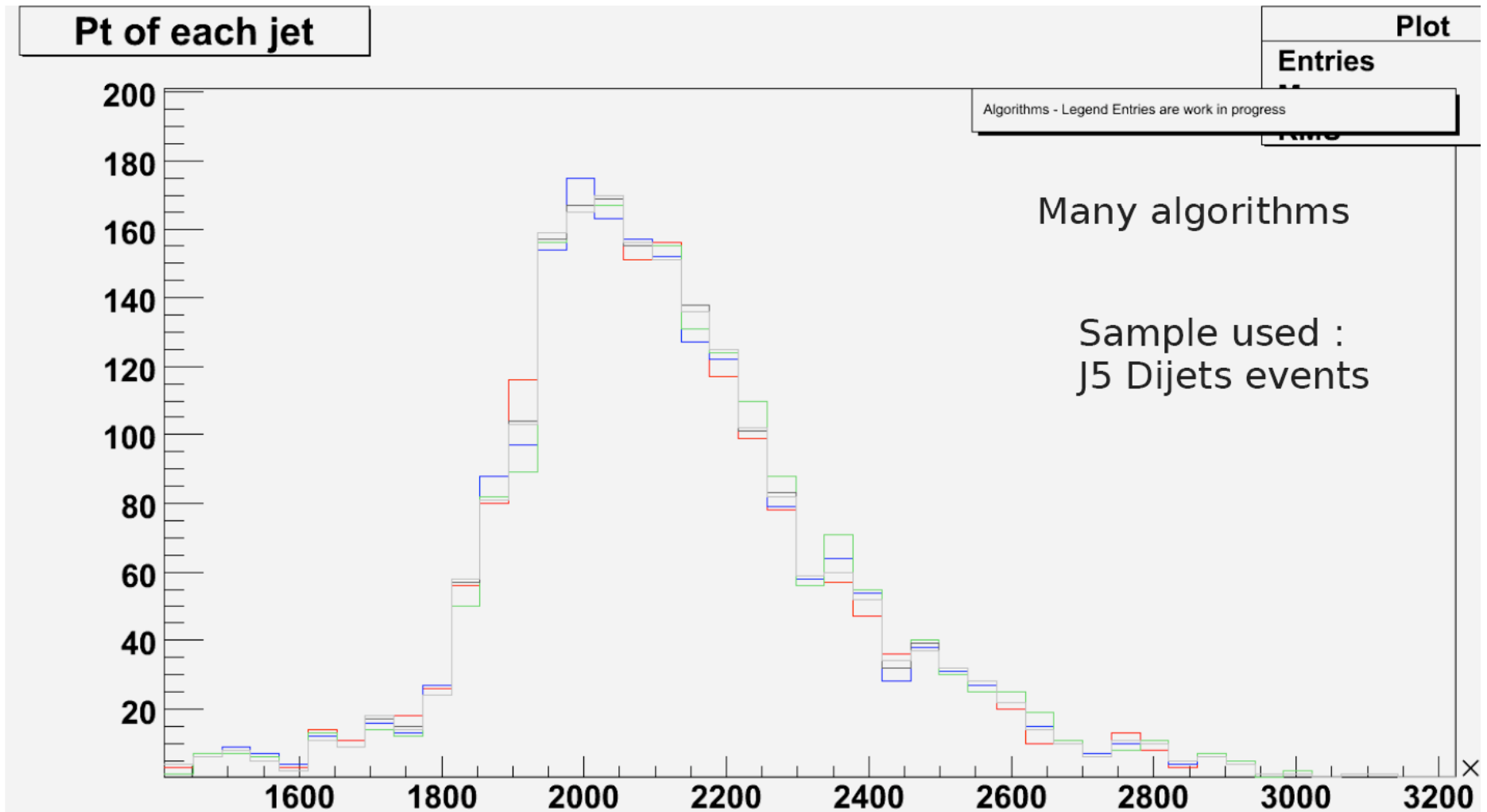
Gui interface



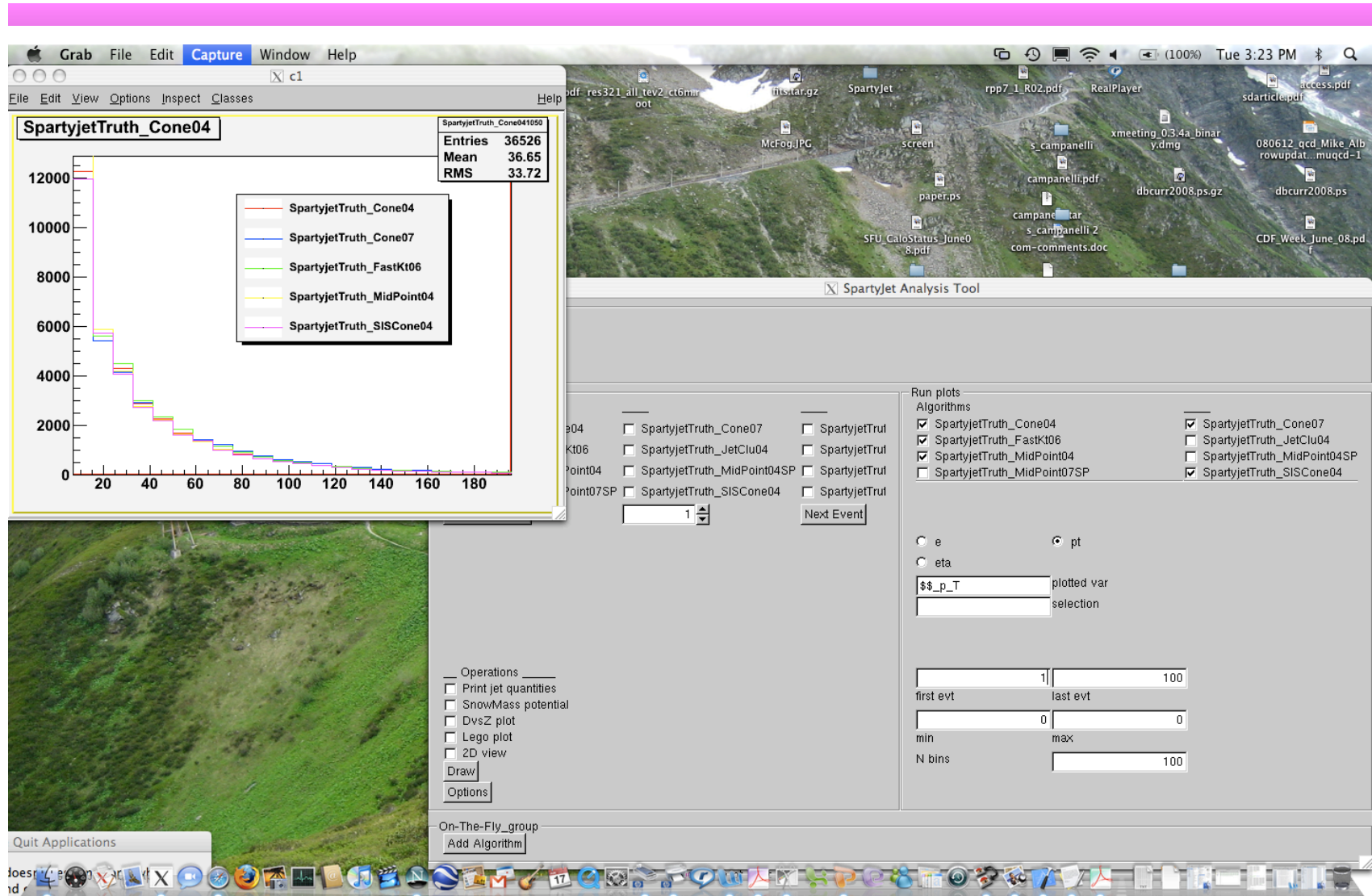
- 0** Number of plots in canvas
- 1** Event-by-event gui
 - What event
 - What algorithm to draw
 - What to plot
- 2** All sample plots
 - ~interface to TTree::Draw



2:Interactive plots

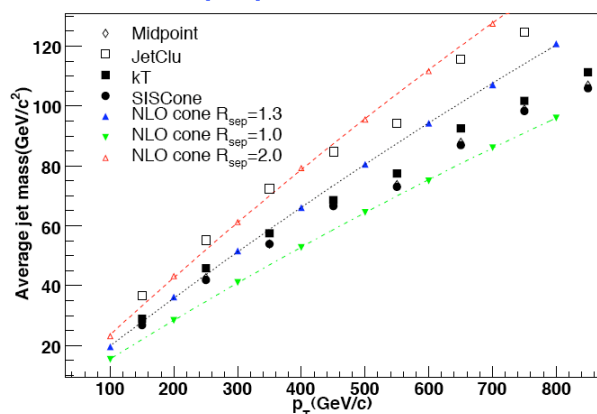


Laptop running



Jet masses

- It's often useful to examine jet masses, especially if the jet might be some composite object, say a W/Z or even a top quark



- For 2 TeV jets (J8 sample), peak mass (from dynamical sources) is on order of 125 GeV/c², but with long tail
 - Sudakov suppression for low jet masses
 - fall-off as $1/m^2$ due to hard gluon emission
 - algorithm suppression at high masses

▲ jet algorithms tend to split high mass jets in two

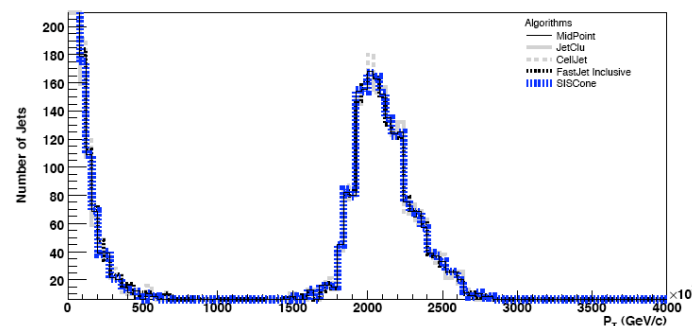


Figure 50: The inclusive jet cross section for the LHC with a $p_{T,min}$ value for the hard scattering of approximately 2 TeV/c, using several different jet algorithms with a distance scale ($D = R_{cone}$) of 0.7. The first bin has been suppressed.

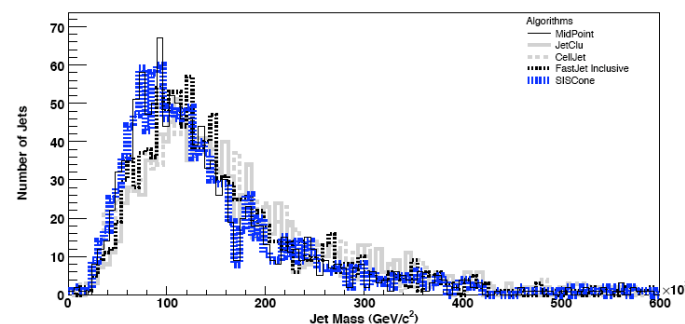


Figure 51: The jet mass distributions for an inclusive jet sample generated for the LHC with a $p_{T,min}$ value for the hard scattering of approximately 2 TeV/c, using several different jet algorithms with a distance scale ($D = R_{cone}$) of 0.7. The first bin has been suppressed.